A SURVEY OF EARTH RESOURCES ON APOLLO 9 PHOTOGRAPHY

by

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and other personnel of the

FORESTRY REMOTE SENSING LABORATORY

SCHOOL OF FORESTRY AND CONSERVATION,

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(NASA-CR-142900) A SURVEY OF EARTH RESOURCES ON APOLLO 9 PHOTOGRAPHY (California Univ.) 83 p HC $4.75 CSCL 08B

N75-24063

Unclas

G3/43 17575

A report of research performed under

NASA Contract No. NAS 9-9348 for the

EARTH RESOURCES SURVEY PROGRAM

OFFICE OF SPACE SCIENCES AND APPLICATIONS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Special Report *25 April 1969*

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CHAPTER I

NATURE OF THE EXPERIMENT

Introduction

In March, 1969, the most important photographic experiment in history was performed. By means of a multiple system of cameras operated by the Apollo 9 astronauts, space photography was obtained of various earth resource "test sites" in the United States. The cameras were equipped with special films and filters, some of which had never before been used from spacecraft. Many of these test sites also were photographed, almost simultaneously, from various aircraft operating from flight altitudes that ranged from a few hundred feet to approximately 70,000 feet. In addition, special sensing devices known as "optical mechanical scanners" were operated from aircraft to permit the nearly simultaneous sensing of several of the test sites in a great many wavelength bands of the electromagnetic spectrum, including several bands in the ultraviolet, visible, near infrared and thermal infrared regions. Finally, in selected portions of these same sites, both terrestrial photographs and on-the-ground measurements of radiant energy emanating from representative earth resource features also were obtained at the time of the overflights.

The experiment was performed under auspices of NASA's Earth Resources Survey Program, in cooperation with various other government agencies, including the U. S. Departments of Agriculture and Interior, ESSA, and the U. S. Naval Oceanographic Office. Also under the direction of NASA, several universities and private industrial firms participated in this important data-collection phase.

As will presently be seen, the entire experiment was carefully designed with a view to developing improved capabilities for the inventory of various kinds of earth resources, including timber, forage, agricultural crops, soils, water and minerals.

In this introductory chapter, a rationale for the experiment is developed with emphasis on its great potential importance to mankind. A brief description also is given in this chapter of work that currently is being performed to determine how useful these special kinds of photography might be for the inventory of earth resources. Succeeding portions of the present report will summarize certain activities that already have been performed, and also activities that soon will be performed, to ensure that the tremendous potential of this important experiment will be fully realized.

The Need for Earth Resource Surveys

Mankind soon will be confronted with one of the most serious crises of his existence. Basically, this crisis is developing because the world's population is rapidly increasing at the very time when many of its natural resources have dwindled to a very low level. The supply vs demand problem is made even more serious by another recent development: Within the past decade a greatly increased "awareness of the have nots", both in the United States and elsewhere, combined with an almost insatiable demand of "the affluents" for an ever-higher standard of living, has resulted in a tremendous increase in the *per capita* demand for earth resources at virtually every economic level.

Three brief examples will be given which are merely symptomatic of the impending crisis: (1) The Food and Agricultural Organization of the

United Nations has stated that, to provide a decent level of nutrition to the world's people, the production of food will have to be doubled by 1980 and trebled by 2000. (2) In recent testimony given to the U. S. House of Representatives by personnel of the lumber and housing industries there was a concensus that 26 million homes must be built in the United States during the next decade. This represents a construction rate nearly triple that of the present time, with a proportionate increase in the demand for lumber and other construction materials. (3) Experts from the U. S. Department of Interior have repeatedly warned that the presently-known reserves of copper, lead, zinc and many other important non-renewable mineral resources will be exhausted within the next two or three decades at the estimated rate of consumption.

In view of the critical circumstances that are suggested by these brief examples, we need the wisest possible management of the Earth's resources. An important first step leading to such management is that of obtaining accurate resource inventories, quickly and at frequent intervals.

Rationale for the Use of Aircraft and Spacecraft When Making Earth Resource Surveys

There are two primary reasons why earth resource surveys might best be made through the use of aircraft and spacecraft:

The first of these is clearly implied in the simple statement that "the face of the land looks to the sky". The task of inventorying the earth's resources is, first of all, one of delineating boundaries between one resource characteristic and another. When confined to earth, man often has great difficulty both in recognizing and in delineating these

boundaries. This difficulty is attributable mainly to the limited visibility of terrain features that is afforded him, especially in areas where the topography is heavily dissected. An examination of illustrations appearing in succeeding portions of the present report will serve to document this important point. Many of the examples consist of "matched pairs" in which the terrain is portrayed both in the vertical view that is obtainable from aircraft or spacecraft and in the terrestrial or low-level oblique view to which the ground observer is limited. A comparison of such photo pairs will serve to illustrate how much more easily and accurately a "continuous plotting" of these resource boundaries can be performed on the vertical photos.

The second reason for using aircraft or spacecraft results from the sheer vastness of the areas in which earth resource surveys must be made. Ordinarily it is only from aircraft or spacecraft that the broad synoptic view, so essential for the quick and economical delineation of earth resource features can be obtained. The fact that such vast areas can be viewed at a single point in time and under relatively uniform lighting conditions constitutes an additional advantage. The ability of the aircraft or spacecraft to travel quickly from one camera station to another is a related advantage of great importance.

Perhaps another advantage of the view obtained from air or space should be mentioned, even though it is somewhat corollary to the two advantages already mentioned: Without the ability to view subtle lineaments and other patterns simultaneously over a vast areal extent, the resource analyst might never become aware of their existence. Often it is only by his being able to discern each part of the pattern in relation to all other parts that he will be able to discern the feature and thereby discover important earth resources associated with it.

Finally, mention should be made in this section of the fact that aerial and space views of the surface of the earth frequently can complement each other. The broad synoptic view obtained on space photography can be used to maximum advantage in drawing boundaries which discriminate one type of resource feature from another. Then, through a process known as "double sampling", very large scale aerial photography can be obtained of small representative areas within each such type in order to identify it.

Rationale for the Use of Multiband Black-and-White Photography

On the Apollo 9 mission, perhaps for the first time in history, simultaneous multiband photographs of the surface of the earth were obtained from space. We need clearly to recognize the potential usefulness of such photography in the making of earth resource surveys.

Our ability to inventory earth resource features on multiband photography rests on the fact that every type of feature encountered on the surface of the earth tends to reflect and emit radiant energy in distinctive amounts at certain specific wavelengths. Consequently, when remote sensing is done simultaneously in each of several wavelength bands (a process variously known as "multiband sensing", "multispectral sensing" and "multiband spectral reconnaissance"), each type of feature theoretically becomes identifiable by virtue of its multiband "tone signature" or "spectral response pattern".

It was with this possibility in mind that a special Photographic Team, operating under auspices of the NASA Earth Resource Survey Program, held a series of meetings, extending over a period of more than two years, primarily for the purpose of selecting the three bands which would be most useful in a multiband space photography experiment.

Consistent with the recommendations of that team, the three bands used on the Apollo 9 mission in obtaining simultaneous black-and-white photographs from space were those exposing for the green, visible red and infrared wavelengths of radiant energy, respectively. Also, consistent with the recommendations of that team, these same three wavelength bands are to be employed on ERTS-A, the first in a series of Earth Resources Technology Satellites, which is now scheduled for launch in 1971.

Some investigators, on noting that a color film known as "Infrared Ektachrome" contains three dyes which, in effect, are responsive to the green, red and infrared wavelength bands, respectively, have argued that this single color film would be able to provide all of the information obtainable from the corresponding three black-and-white photographs. In order to evaluate this argument, a fourth camera, containing Infrared Ektachrome film, was used on the Apollo 9 mission simultaneously with the three cameras that employed black-and-white films. This 4-camera package (consisting of 4 Hasselblad cameras having 80mm focal lengths and accommodating 70mm roll films) was designated by the NASA Photo Team as Scientific Experiment No. 065. Hereafter in this report, as elsewhere in the literature, this portion of the photography obtained on the Apollo 9 mission will be termed merely the "S065" photography.

In rebuttal to the Infrared Ektachrome enthusiasts, proponents for obtaining three separate black-and-white photographs have cited the following theoretical advantages of so doing, all of which can now be evaluated in very practical terms because meaningful earth-resource test-sites were so successfully photographed with the S065 multiband camera system:

1. When three black-and-white photos are obtained simultaneously, but in three separate wavelength bands (as in the S065 experiment), each film can be given optimum exposure. The potential importance of this consideration is obvious when we emphasize that the optimum exposure that was required when photographing from space with one of the S065 black-and-white photos (that exposing for infrared wavelengths) was 1/250 at f16, whereas that for another of the black-and-white photos (that exposing for green wavelengths) was 1/125 at f4. This represents an exposure difference in the two bands of 5 full stops. Consequently, a single color film such as Infrared Ektachrome that seeks to expose for both of these bands simultaneously does not lend itself to any compromise in f-stop and shutter speed settings that will provide comparably good exposures.

2. In the black-and-white 3-camera system, each lens can be set at optimum focus for the narrow range of wavelengths used when taking pictures with it. Again, actual figures are needed in order to quantify this potential advantage. In the S065 experiment, all cameras used had focal length calibrations which had been emplaced by the manufacturer based on the presumption that normal panchromatic film would be used in them. Consequently, it was entirely appropriate that a focal-setting of "infinity" be used during the Apollo 9 mission on the cameras that were exposing only for green and red wavelengths, respectively. However, a setting of 33 feet (instead of infinity) was found to provide optimum focus for the third Hasselblad camera, since it was exposing only for relatively long wavelengths which are focussed at a much different distance than are the green and red wavelengths. The fourth camera of the S065 system (the one using Infrared Ektachrome film) had to be focussed at 50 feet, in an effort to obtain the best compromise in focal

settings, realizing that green, red and infrared wavelengths had to be recorded simultaneously by it.

Methods Used in Enhancing the S065 Photography

If all of the useful information that is contained in three separate black-and-white multiband photographs is to be conveniently analyzed, some means of correlating the three images is needed. In our analysis of the S065 black-and-white photography, four methods are being used to accomplish this image correlation.

In the first method, multiband imagery of a given portion of the terrain is reconstituted as a single color composite. Each type of feature is then identified merely through visual perception of the color exhibited by it in the composite color imagery. When this method is employed, it is common practice to project simultaneously onto a viewing screen all of the black-and-white images of a given portion of the terrain that have been obtained with the multiband reconnaissance system. The color rendition is achieved by the use of colored filters. Each black-and-white frame is projected, in lantern slide form, through a filter of suitable hue. For any feature, the intensity of that particular hue as seen on the color composite is governed by the grey scale (tone) value exhibited by the feature on the corresponding black-and-white lantern slide.

In the second method, a battery of photo-electric (brightness sensitive) scanners is used to scan all of the multiband black-and-white images simultaneously. For each of the multiband images of a given area of terrain a scanner is assigned. The scanners, operating in unison, scan the black-and-white multiband images line-by-line, progressing from the

top of the frame to the bottom. Because all of the multiband images have identical geometry, all of the scanners simultaneously view conjugate images (i.e., images of the same terrain feature). Consequently, a multiband "tone signature" or "response pattern" is read out by the battery of scanners for each "x" and "y" coordinate position appearing in the multiband imagery. Ordinarily a previous "calibration phase" will have determined what the unique multiband tone signature is for each type of feature that is to be identified. Consequently, in the operational phase each resource feature is identified merely by a spectral matching technique which compares its multiband tone signature with this previously-derived master set of tone signatures. At present such a method has not been perfected, but even with its present limitations, it is able to provide sufficient automatic image analysis to greatly reduce the amount of work that must be done by the image analyst himself.

In the <u>third</u> method, the same three black-and-white transparencies as were used in the optical combiner (method 1)are scanned with a closed circuit color television system. (The device known as "IDECS", which has been developed by the Center for Research in the Engineering Sciences, University of Kansas, was used in the present study). As one transparency is scanned, its brightness values govern the intensity of the <u>red</u> phosphor of the color television screen; a second band governs the intensity of the <u>green</u> phosphor; and the third band governs the intensity of the <u>blue</u> phosphor. The resulting color composite image, as seen on the screen, can be photographed and presented, as in succeeding sections of the present report.

Although not applicable to the S065 photography itself, there is a <u>fourth</u> method of correlating the multiband "signals" from an earth resource

feature. The method is applicable to the analysis of multiband data obtained with an optical mechanical scanner, and hence is being employed to analyze certain of the records obtained from supporting aircraft that flew simultaneously with Apollo 9, as previously mentioned. In order that this fourth method can be employed, the multiband sensing system must record on magnetic tape, rather than on photographic film, the signal strength emanating from each object in each spectral band. Thereafter, the procedure is essentially the same as it is in the photoelectric scanning technique that was described under the second method. Potentially, there is a highly significant difference between the two methods, however. This fourth method is theoretically capable of providing a complete inventory ofearth resources only moments after the remote sensors have been flown over the area of interest. It also makes possible an analysis of signal strengths emanating directly from the sensed objects, whereas in the second method the analysis is of signals that may have been degraded in the process of forming multiband images of the object.

In the present report, the first and third of these methods, as applied to the S065 photography, will be illustrated, and in some instances directly compared. Examples of the fourth method, based on optical mechanical scanner records obtained from supporting aircraft, also will be included. With the time constraints of the present "30-day report" it has not been possible to obtain photo-electric scans of S065 imagery so that the second method cannot be included here for comparative purposes. Such comparisons are being made, however, and will be included in a subsequent report. On Apollo 9 many hand-held photos also were taken with 70mm Ektachrome film to complement the 4-band S065 photography. Some of these are presented in the present report.

CHAPTER II

ANALYSIS OF EARTH RESOURCES IN THE PHOENIX, ARIZONA AREA

by

D. M. Carneggie, L. R. Pettinger, and C. M. Hay

The S065 photography analyzed in this chapter was obtained from Apollo 9 on March 12, 1969 at approximately 8:30 a.m. from an altitude of 126 nautical miles. The area is roughly centered around Phoenix, Arizona, and extends from Gila Bend, approximately 150 miles west of Phoenix, to a point more than 100 miles to the east of Phoenix in the vicinity of Roosevelt Lake.

Within this vast area (more than 20,000 square miles) several sites were selected which were representative in terms of the earth resource features exhibited within them. For these selected sites "ground truth" was obtained at the time of the Apollo 9 overflights to provide an accurate record of the earth resources with in them. By means of this ground information, together with nearly simultaneous low altitude aerial oblique photos, it has been possible to demonstrate both the uses and the limitations of space photography for evaluating earth resources in the Phoenix area.

Among the illustrations included in this chapter are space photographs, low altitude aerial oblique photographs and a few color composite photographs. The latter were prepared by the first of four methods discussed in Chapter 1. The captions accompanying these various illustrations are designed to permit the reader to make his own evaluations of the tremendous potential of space photography as an aid to the making of earth resource inventories. In addition, a Feasibility Chart is included near

the end of the chapter[6], to summarize important conclusions of the investigators and to indicate the potential usefulness of "double sampling" techniques of the type mentioned in Chapter I.

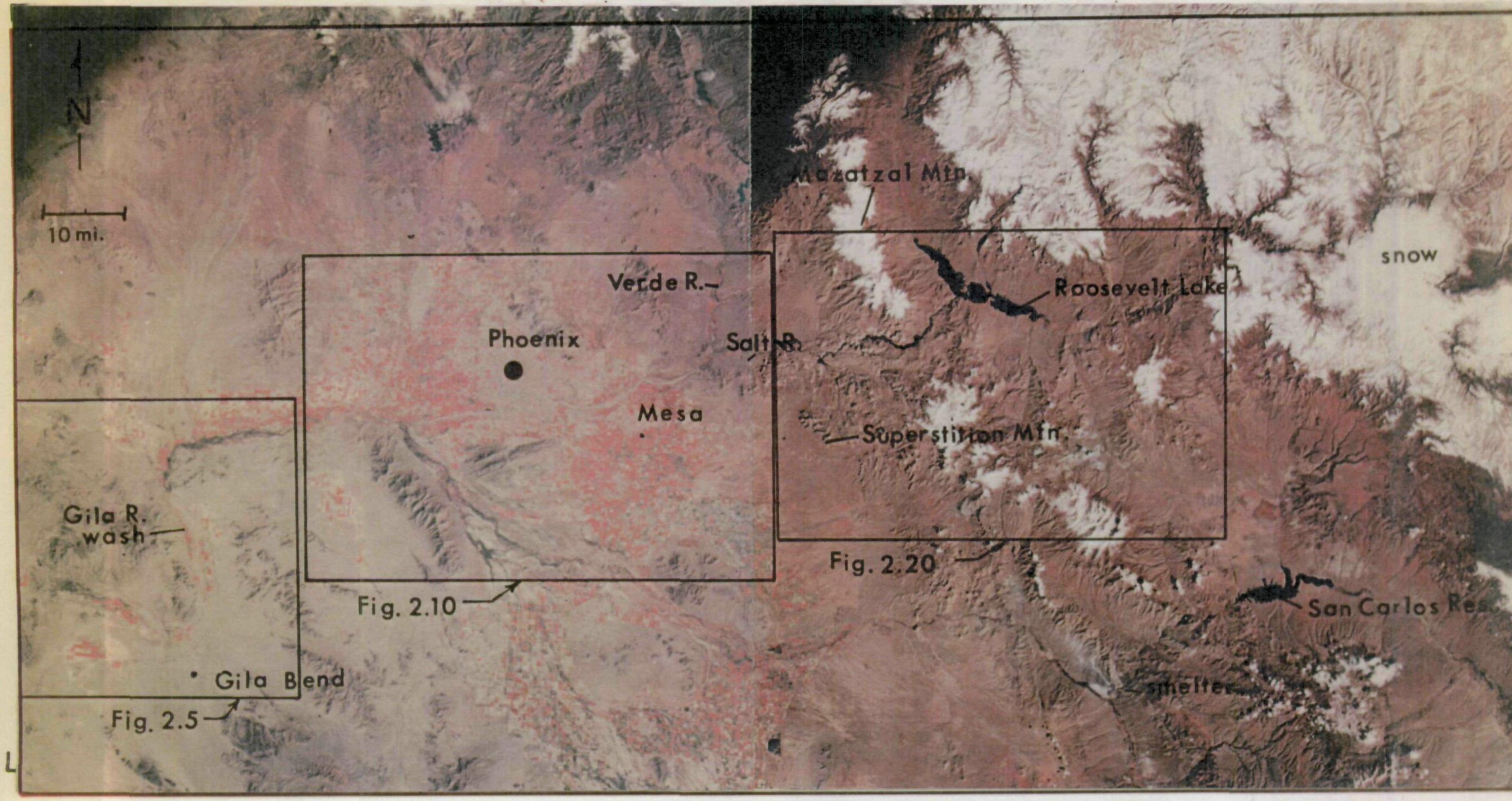
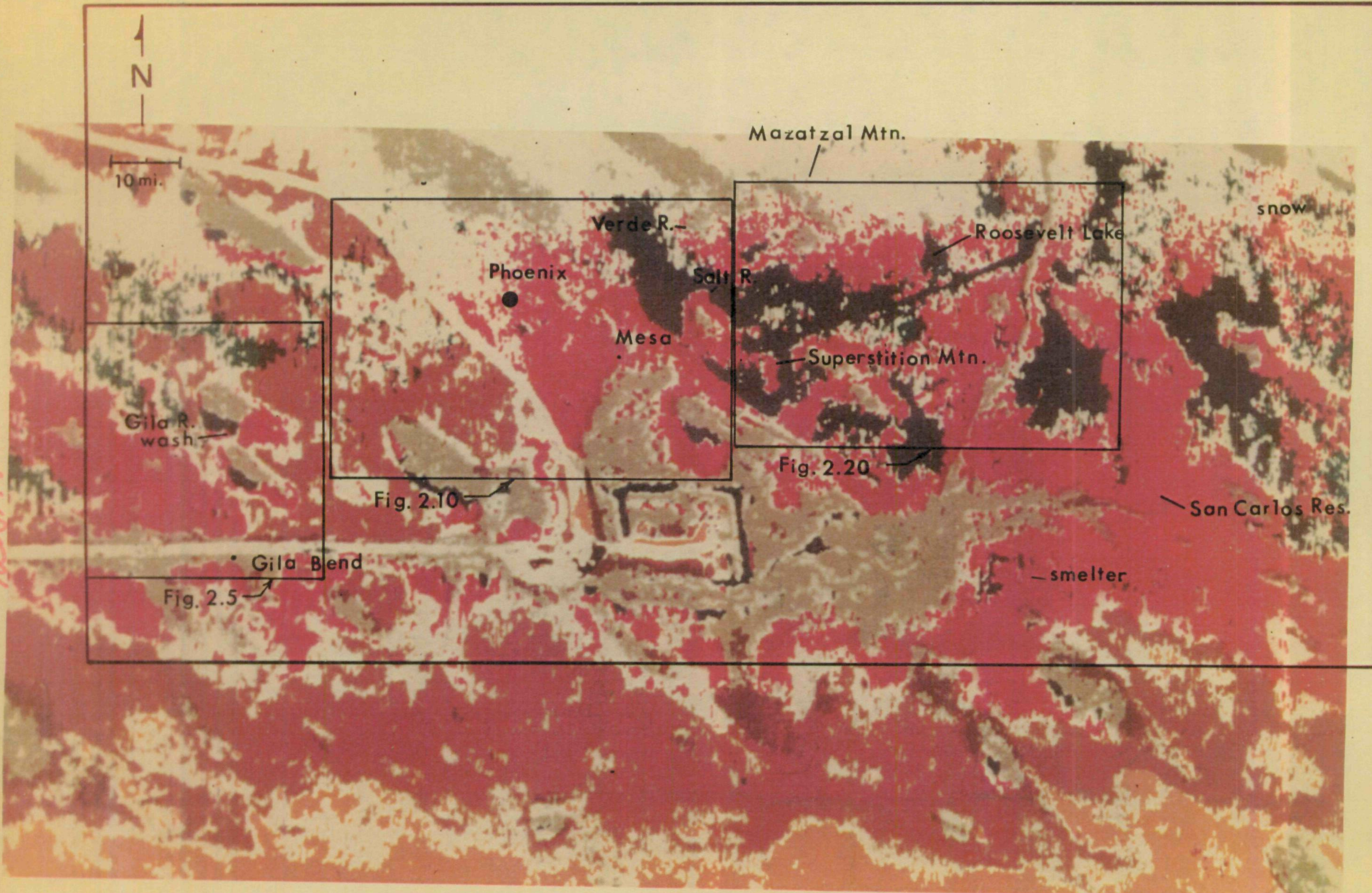


Figure 2.1 This Infrared Ektachrome space photo mosaic shows the land use patterns and resource features within a 20,000 square mile area that included Phoenix, Arizona. On the acetate overlay some of the more conspicuous geographical features have been annotated. The three rectangular areas indicated appear as enlargements in subsequent figures of this chapter and bear the numbers designated. For each of the three areas the broad resource features have been delineated on subsequent figures and are evaluated in the accompanying captions, text and tables. Conspicuous among the features that can be differentiated on the space photos shown in this figure (2X magnification) are (1) the agricultural land, denoted by the conspicuous blocks of red fields (planted crops) interspersed with the non-planted cultivated fields that appear light tan or black in color depending upon the soil type and how recently the field has been tilled; (2) the uplands and mountains; (3) the open shrubland used for grazing; (4) the watercourses and drainage networks; (5) large catchment basins; (6) snowfields and (7) urban areas. Compare the ease of detecting and evaluating these broad resource categories on the above S065 color infrared photos with the matching black-and-white S065 photos seen in Figures 2.2, 2.3 and 2.4.


N
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Phoenix
Salt R.
Roosevelt Lake
snow
Mesa
Superstition Mtn.
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Fig. 2.10
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San Carlos Res.
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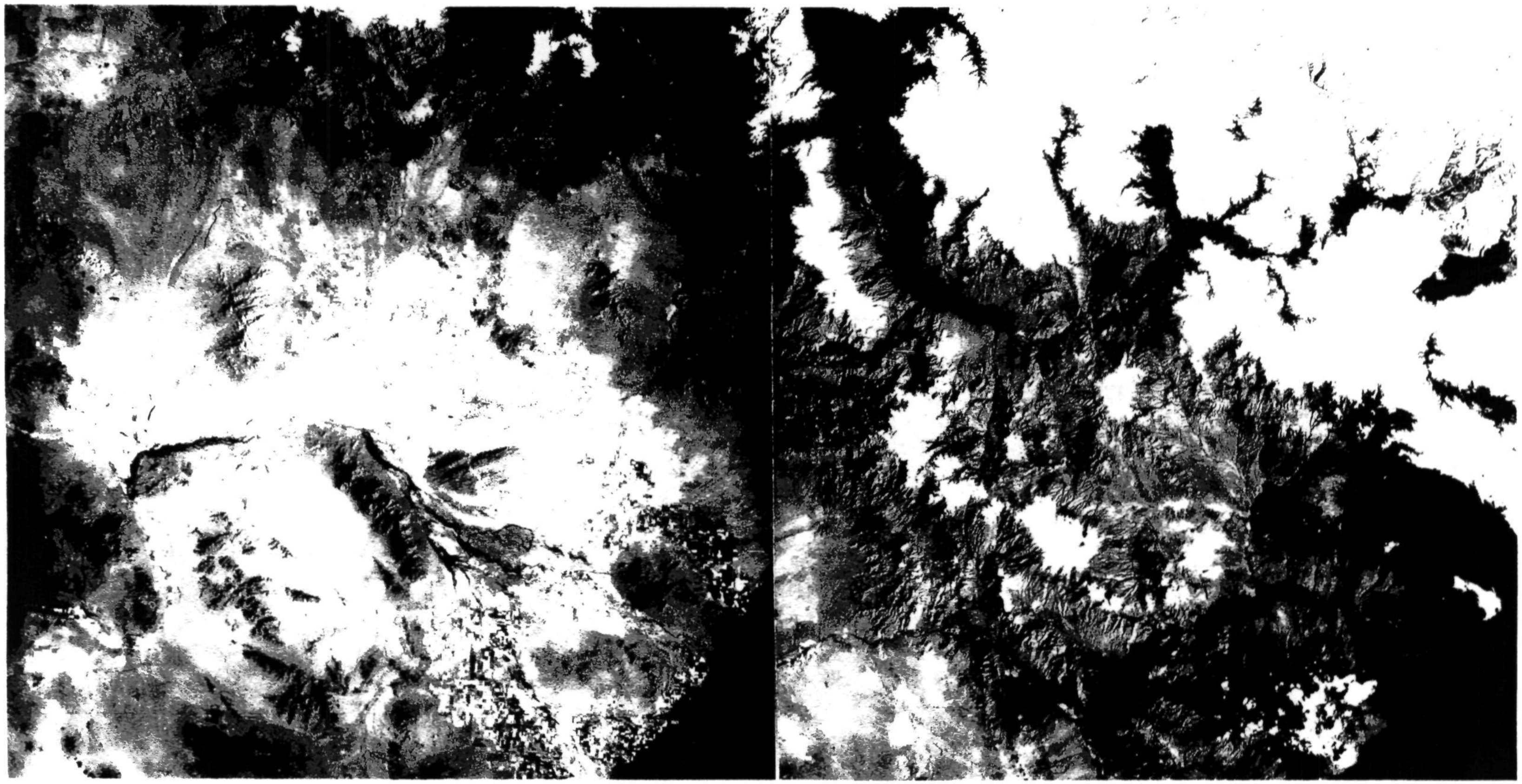


Figure 2.2 Black-and-white space photo mosaic obtained in the S065 experiment by exposing for near-infrared wavelengths of radiant energy. Large reservoirs, snow, clouds and agricultural areas can be readily detected. Planted cereal crops and alfalfa fields appear white but in some instances are not easily differentiated from light soils or land set aside for urban development. Urban areas are not conspicuously seen; however, major thoroughfares in Phoenix can be seen. Native vegetation and soil boundaries, as well as dirt roads, are not as conspicuous on these photos as on the Infrared Ektachrome photos of Figure 2.1.

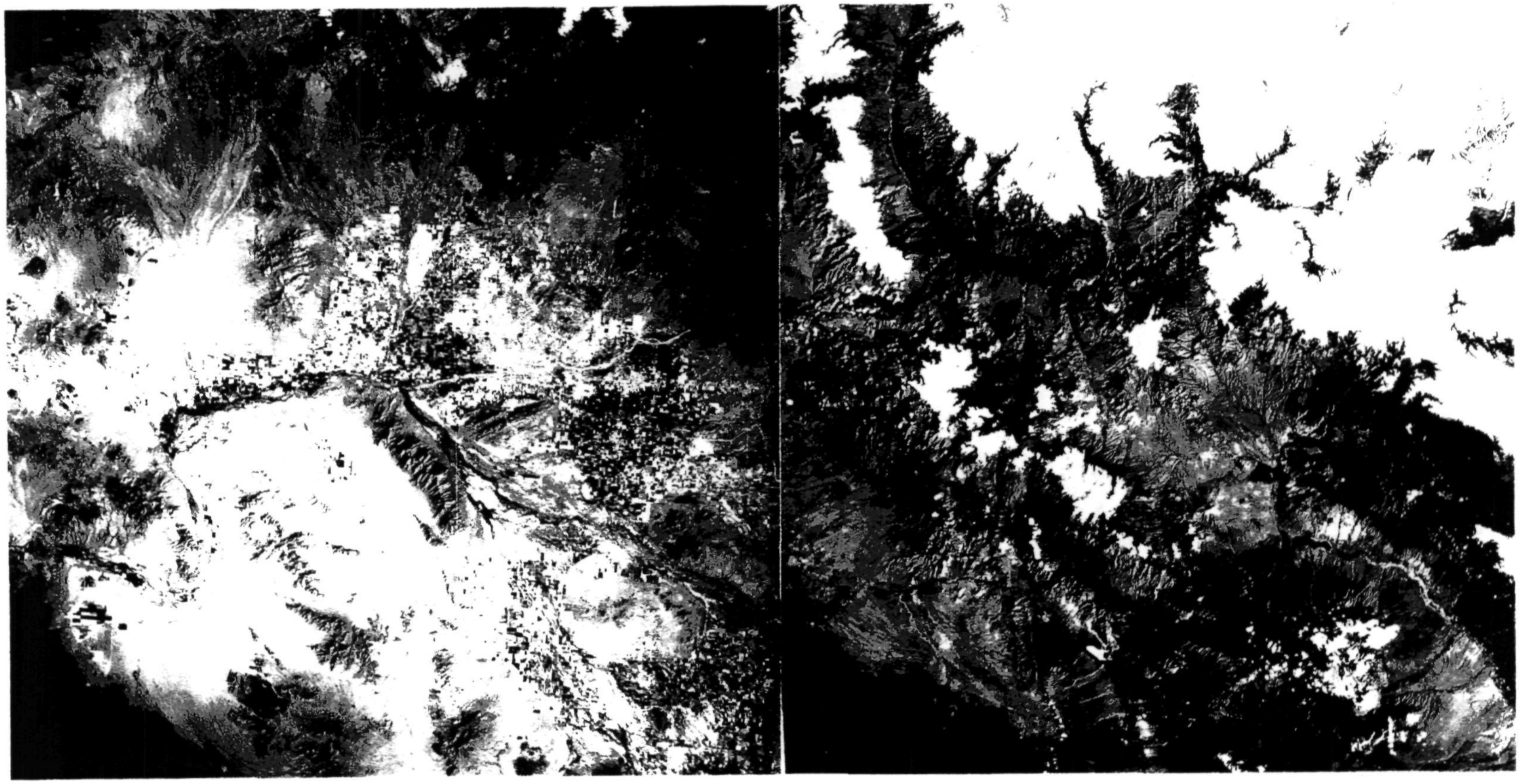


Figure 2.3 Black-and-white panchromatic space photo mosaic obtained in the S065 experiment by exposing for visible red wavelengths of light. The filter used (Wratten 25A) blocks out reflected green and blue wavelengths of light; hence, vegetation and water appear dark in tone. Fields of barley, wheat, alfalfa and other "continuous cover" crops appear dark in tone relative to the fields of recently tilled soil; consequently, agricultural crops are readily delineated. Because agricultural fields covered by various crop types appear similarly dark in tone, the separation of major crop types is not feasible on this photography. Urban areas surrounded by the agricultural land are easily detected; however, road networks within the cities are not observable. Dirt roads and other features which have disturbed the native vegetation are more readily seen on these photos than on the black-and-white near-infrared photos of Figure 2.2.

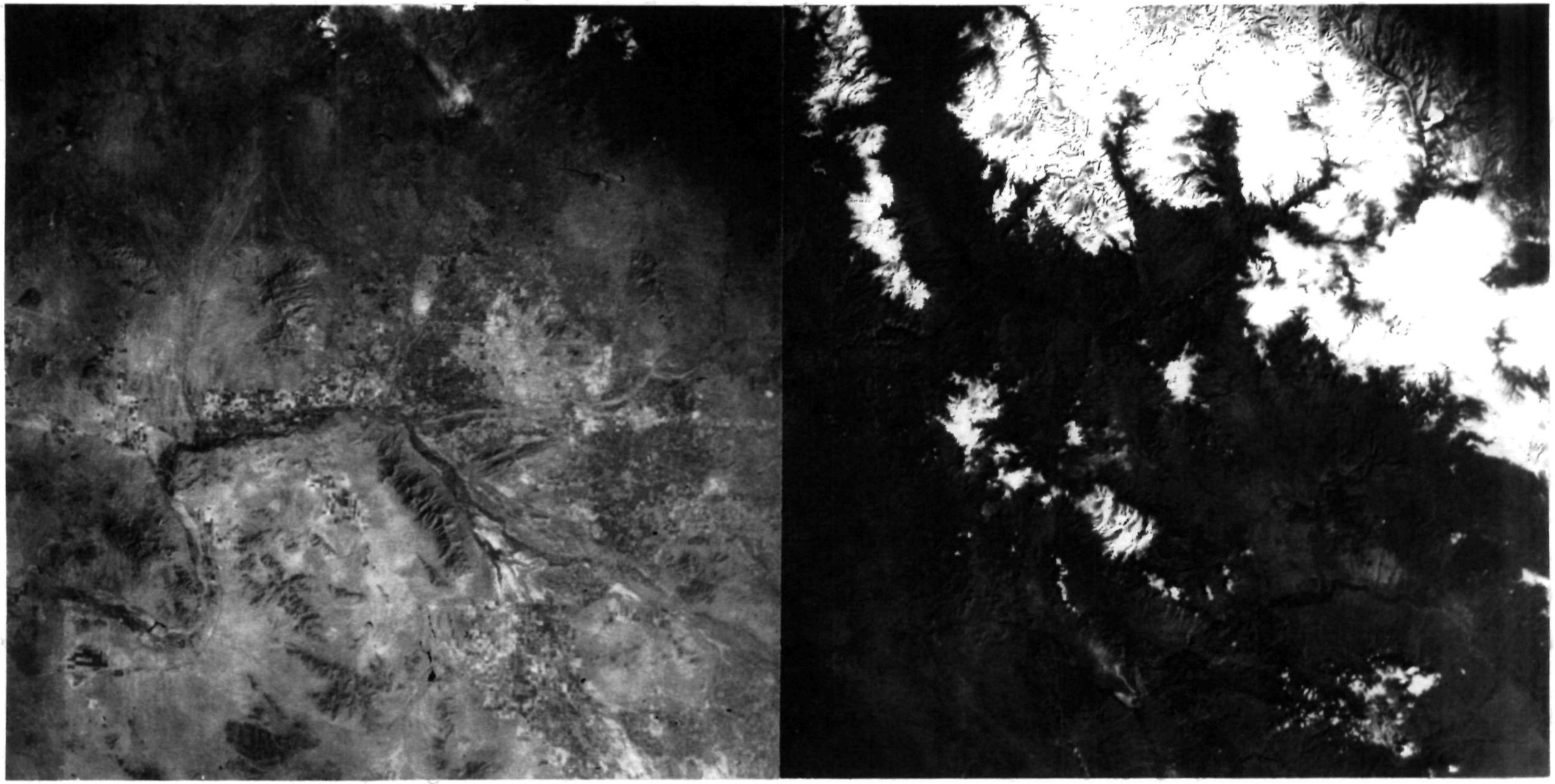


Figure 2.4 Black-and-white panchromatic space photo mosaic obtained in the S065 experiment by exposing for green wavelengths of light. As in the previous two black-and-white photos, snow and clouds are readily detected; however, water bodies although detectable are not so conspicuous. In addition, the distinction between agricultural fields with and without crops is not as readily made. The towns of Phoenix, Tempe, Mesa and Chandler are easily detected, but road networks are not discernible. Cultural features and disturbances within the native vegetation types are not as easily seen on these photos as on the Infrared Ektachrome or panchromatic photos appearing in Figures 2.1 and 2.3 respectively.

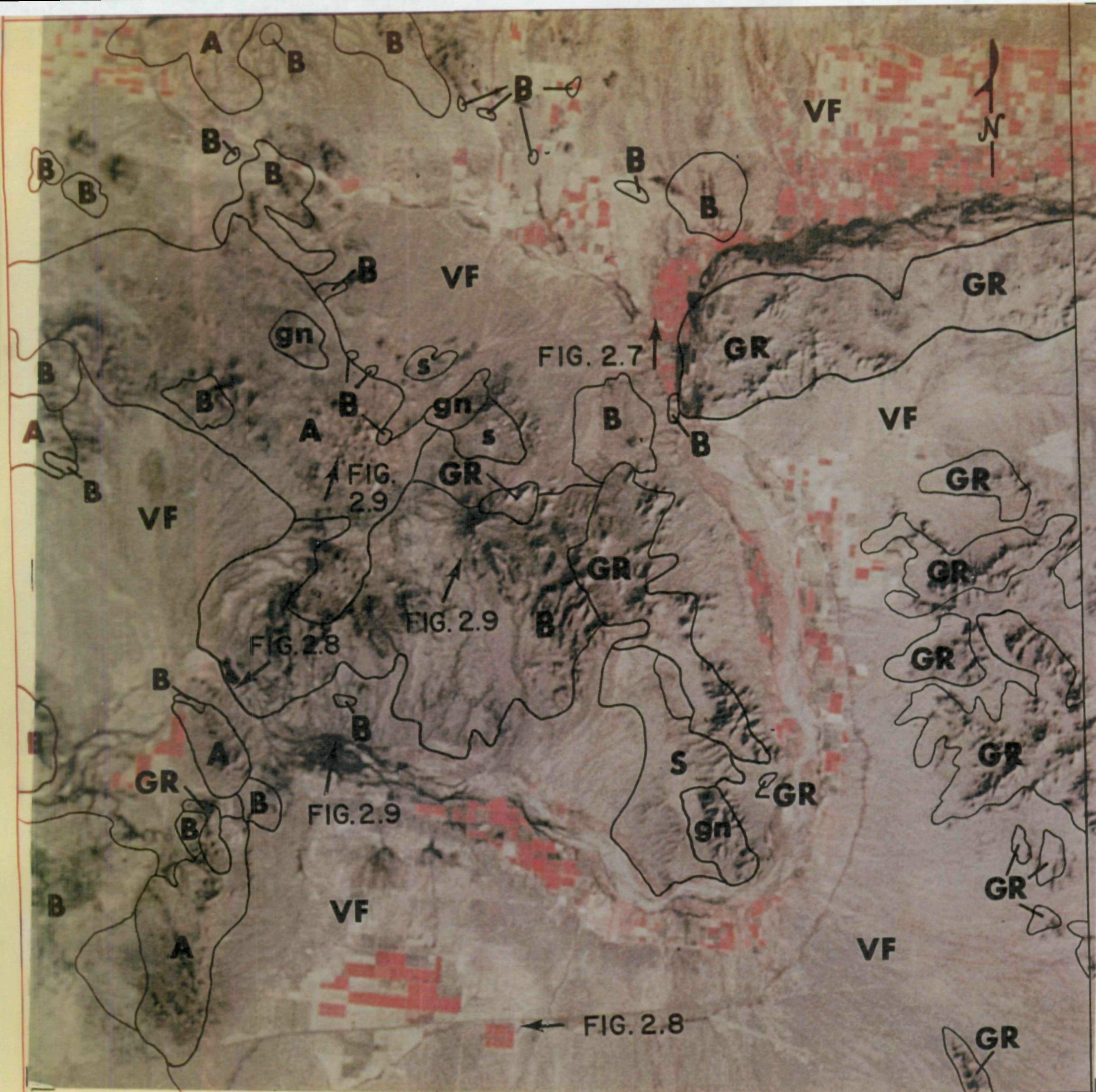


Figure 2.5 Geologic overlay of color infrared photo, Gila Bend area, Arizona. The overlay was prepared with reference to the Arizona Bureau of Mines Geologic Map of Maricopa Co., and adjustedin conjunction with discernible geologic data from the photo.

Present are a variety of rock types: Igneous - basalt (B) andesite (A), granite (GR); Metamorphic - schist(s), granitic gneiss (gn); and Sedimentaries (S) consisting of clastic material. Most of the area is covered with unconsolidated valley fill (VF). Areas of valley fill can be quickly differentiated from bedrock by the topographic configuration, uniform tone and parallel drainage pattern of the fill.

Lithologic distinctions within bedrock areas can be made in some places using tone and textural differences. See Fig. 2.9. Boundaries between lithologic units were not always distinct, however. Lack of stereographic coverage hindered the delineation of many boundaries without aid of the geologic map. Many more would have been discernible in stereo without the aid of the map. The low sun angle, while accentuating the topographic forms, eliminates subtle tone differences which may be valuable in identifying lithologic types.

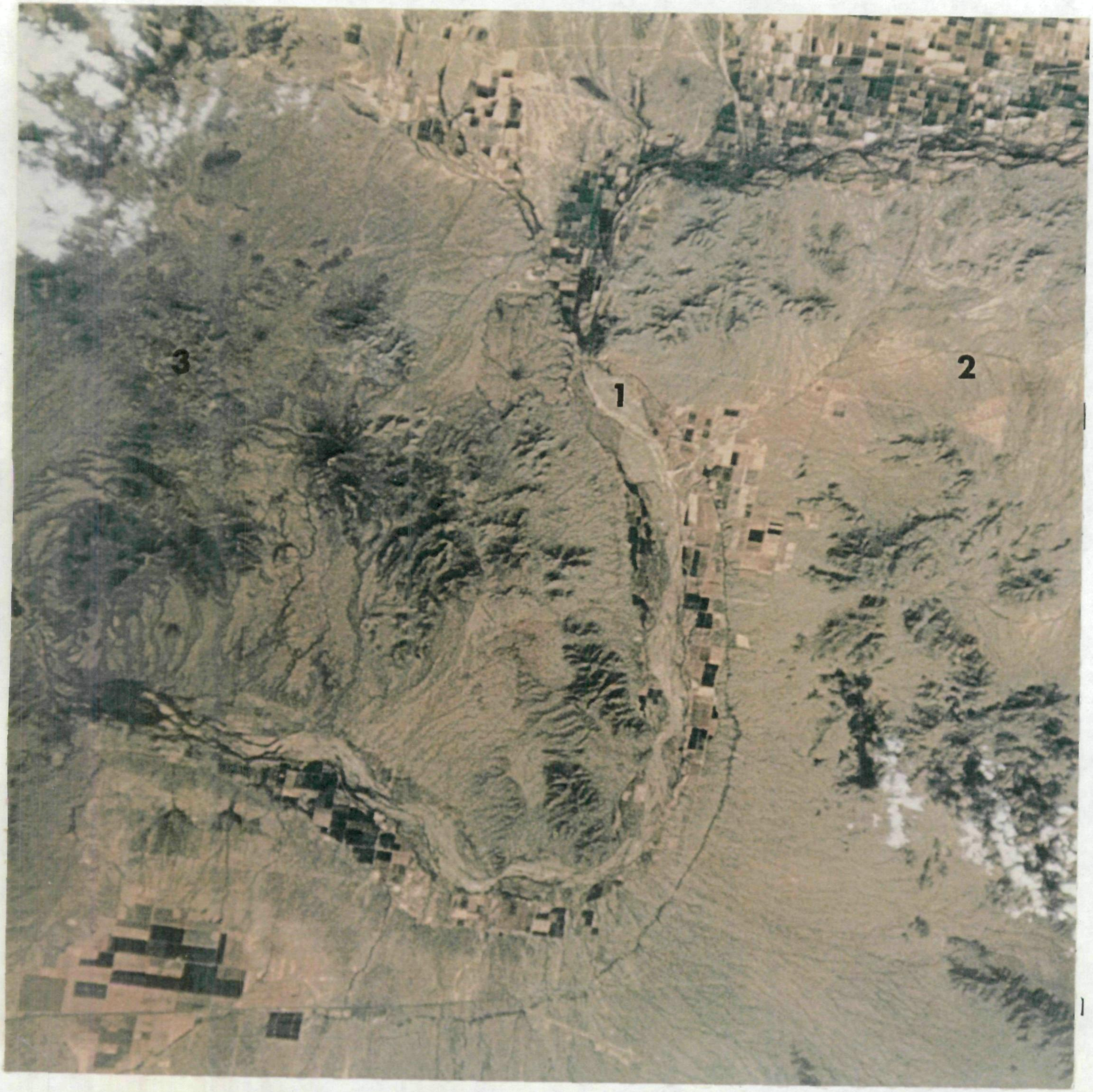


Figure 2.6 On this Ektachrome photo of the Gila Bend area many terrain features of interest to a geologist-geomorphologist stand out more clearly than on the Infrared Ektachrome photo. The alluvium in the low water stream channel (1) is better contrasted with the adjacent alluvium occupying the remaining portion of the channel which is covered only in times of high water. Thus the Ektachrome print may be more valuable in a study of sedimentation processes in these kinds of stream channels. Also, drainage patterns in the valley fill (2) are more clearly defined on the Ektachrome photo than on the Infrared Ektachrome photo.

The Infrared Ektachrome photo (Fig. 2.5) permits the andesite (3) to be more easily distinguished from the basalt. On this Ektachrome print the differentiation between the two can still be made, but here the difference in textural patterns is a more useful discriminating criterion because the tonal difference is not as apparent.

Figure 2.7 Low altitude Infrared Ektachrome aerial oblique photograph which shows the abrupt boundary between (a) the mesquite-forest vegetation (right) that occupies the Gila River watercourse, (b) the agricultural crops consisting mainly of alfalfa and barley, and (c) semi-desert shrub rangeland. These distinctive boundary lines can be seen quite readily on the space photo in Fig. 2.5. Note that the basalt structures seen in the rangeland can be seen on the low altitude oblique as well as on the space photo. At the time the space photo was taken the dense forest of mesquite trees along the watercourse had not begun to leaf-out; hence, this vegetation type appears black on the space photo (one may at first mistake this to be river water). Note also that the agricultural fields which do not presently have a cover crop can be readily differentiated from those fields which do have a cover crop.

Figure 2.8 The top two low-altitude aerial oblique photos (Kodacolor, left; Infrared Ektachrome, right) look west along Interstate Highway 8 and show agricultural cropland that has been converted from the native semi-desert shrub rangeland. The crops in the lower left of the photo are alfalfa hay fields. Color differences among these fields reflect density differences of the standing alfalfa due to the age since the last cutting. These differences are detectable on the space photo in Figure 2.5. The planted fields in the upper right are mainly wheat that has not yet produced seed heads. The leaves were approximately 15" in length when the space photo was taken. Notice that wheat and alfalfa fields appear similar on the space photo. The lower two oblique photos show the Painted Rock Reservoir on the Gila River (see space photo in Fig. 2.5). This reservoir provides irrigation water for the crops discussed above. The availability of water is one of the prerequisites for growing crops on rangeland soils.

Figure 2.9 Top Left: Oblique photo of andesite area shows the reddish-brown tone and highly dissected nature of the low rounded hills. The combination of this tone and topographic texture helps make the andesite distinctive from the basalt on the space photo. (See Fig. 2.5).

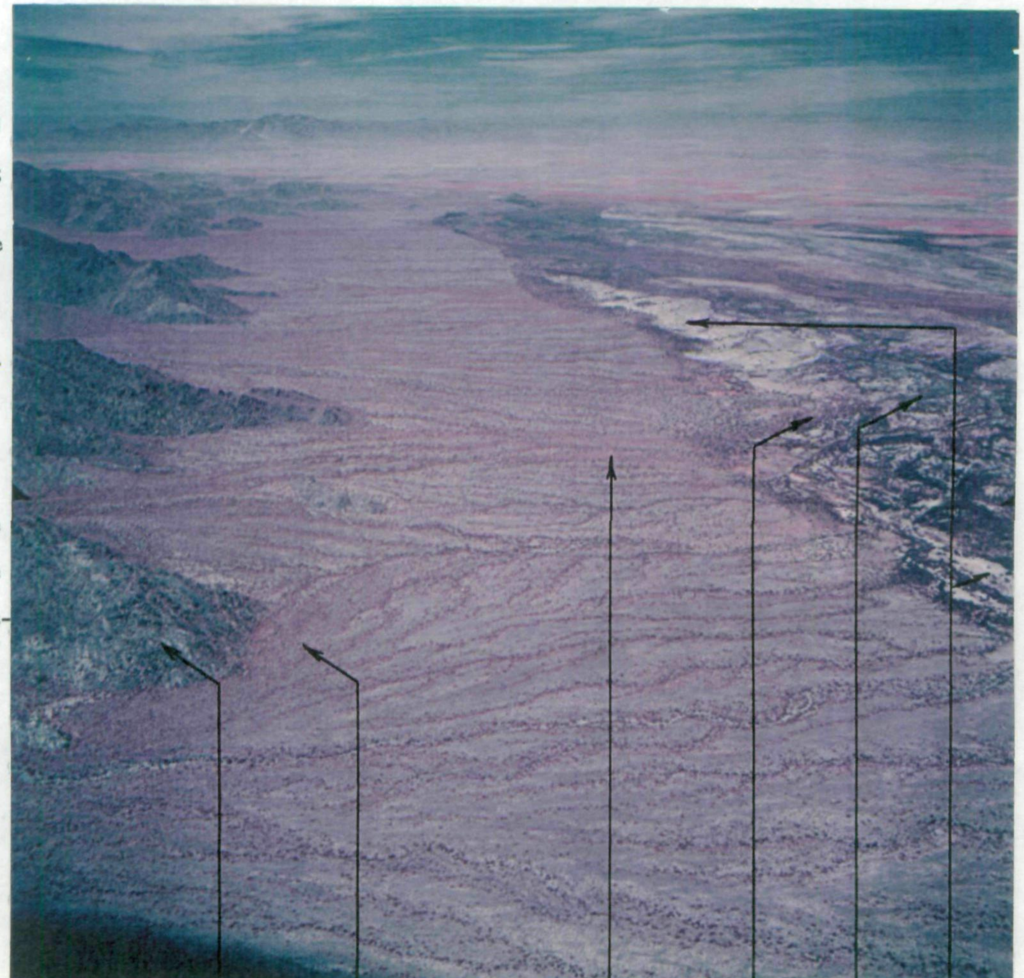
The basalt (bottom left) appears darker in tone than the andesite, and its topographic form is also different in that the basalt has been less eroded and forms longer higher ridges or isolated conical hills. In extensive areas of flatter topography, the basalt is in evidence by the dark black gullies and scarp edges.

Top Right: In the central right portion of the photo are small granite hills which are clearly visible and mappable on the space photo. The light tone of the granite and its topographic form (generally long, thin, acutely branching ridges) distinguish it from the more basic extrusive igneous rocks present. In this area, however, it is interesting to note that the granitic gneiss cannot be easily differentiated from the granite because of their similar tone and topographic form.

Figure 2.10 This Infrared Ektachrome reproduction is a 7X enlargement of a portion of the original space photo (see Fig. 2.1) taken over Phoenix, Arizona. The acetate overlay illustrates how land uses and wildland resources can be readily delineated and identified from an analysis of a space photo. This kind of land use map can be of significant value in planning future development of the resources of this area. The two rectangular areas indicated are enlarged still further in the figures designated.

Figure 2.11 A 14X enlargement from the original Infrared Ektachrome space photo of Phoenix. This same area is also seen at smaller scale in Figure 2.10. Note that in both figures it is a relatively simple task to delineate the significant features and classify them according to land use. The upland areas presently have very little use or value and the area designated "rangeland" receives only limited seasonal grazing. Some of the better sites in this type, however, are potentially valuable for agricultural use if the land can be leveled and irrigated at reasonable cost. The agricultural land is conspicuously made up of large fields of reddish or rust-red crops. Barley, wheat and alfalfa, the predominate crops in this area, appear reddish while citrus appears rust colored. The urban area is distinguished by its characteristic mottled color and by the many main thoroughfares that are discernible. Although features may not appear as sharp at this enlargement, they are easier to see, delineate and measure than on photos that have not been enlarged.

Figure 2.12 Infrared Ektachrome aerial oblique photograph which shows sharp boundaries between uplands (left side); semi-desert shrub vegetation type on alluvial materials from the uplands (central area) and mesquite forest type occupying the watercourse of the Gila River (right side of photo). In the distance one can see agricultural land which is located west of Phoenix. The positions of features seen in this photo with respect to the space photo are indicated in Fig. 2.11. The whitish area in the upper right center is a salt flat (i.e., silt and sedimentary deposits high in sodium salt) which appears conspicuously on the space photo. Note that the uplands are quite steep and have only a sparse cover of vegetation. The semi-desert shrub type here is dominated by creosote bush (Larrea tridentata). Many annual grasses and forbs occupy the interspaces between shrubs and account for some of the pinkish-lavender color associated with this type. Because the forage available is sparse only limited grazing makes up the main use of this type of land. As in Fig. 2.7, the mesquite trees have not leafed out; hence, they appear black on the space photo. This watercourse vegetation provides a favorable habitat for many types of small animals and gamebirds.



In order to achieve the most efficient management and utilization of his resources, the wildland manager must be able to collect and integrate information regarding the physical and biological features of his land. For example, he must recognize important relationships between landform, soil condition, moisture regime and vegetation type so that he can better formulate management decisions that assure a continuous flow of renewable resources without depleting those resources. Such information can be effectively extracted from simultaneous interpretation of space and aerial photographs (illustrated in Fig. 2.11 and 2.12 above) when these relationships are known. The diagram on the right (taken from Lyman Benson and R. A. Darrow, "The Trees and Shrubs of the Southwestern Deserts", The University of Arizona Press, Tucson, Arizona, March, 1954, 437 p.) illustrates that, in fact, a close correlation exists between landform, soil structure, soil texture, moisture regime and vegetation types as found in the southwestern desert. Landforms and associated features almost identical with those in the diagram appear in the wildland environment seen in Figure 2.11 above (located southwest of Phoenix). Thus, by either interpreting landforms and vegetation types of this area from the space photo (Fig. 2.10) or aerial oblique (Fig. 2.11), considerably more information can be inferred about the associated features which will contribute to the wise management of the land.

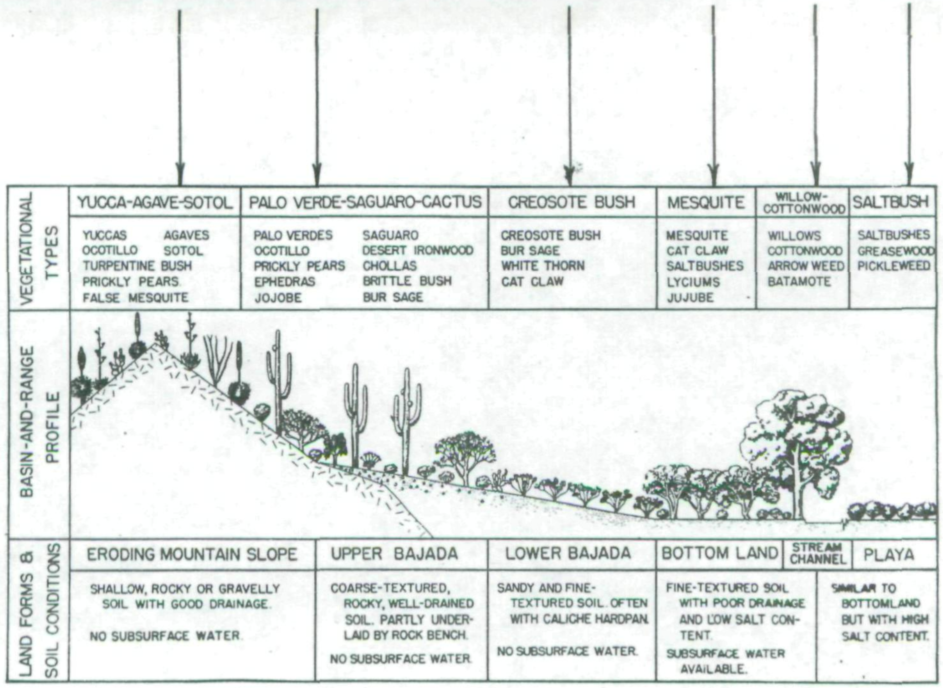


Figure 2.13. The two top oblique photos (Ektachrome and Infrared Ektachrome) show an area at the base of the South Mountains (just south of Phoenix) which is suitable for growing citrus. Note the characteristics of citrus, viz, tree height-shadow pattern, tree spacing and color signature, which permit an interpreter to distinguish citrus from low growing crops such as barley, alfalfa, etc. The Infrared Ektachrome space photo in figure 2.11 shows the position of the above photos. Note that citrus can be distinguished on the space photo by its reddish-brown (rust) color. The bottom photo shows a portion of a semi-desert shrubland type that has been cleared and cultivated in preparation for growing crops. It also is conspicuously seen in figure 2.11.

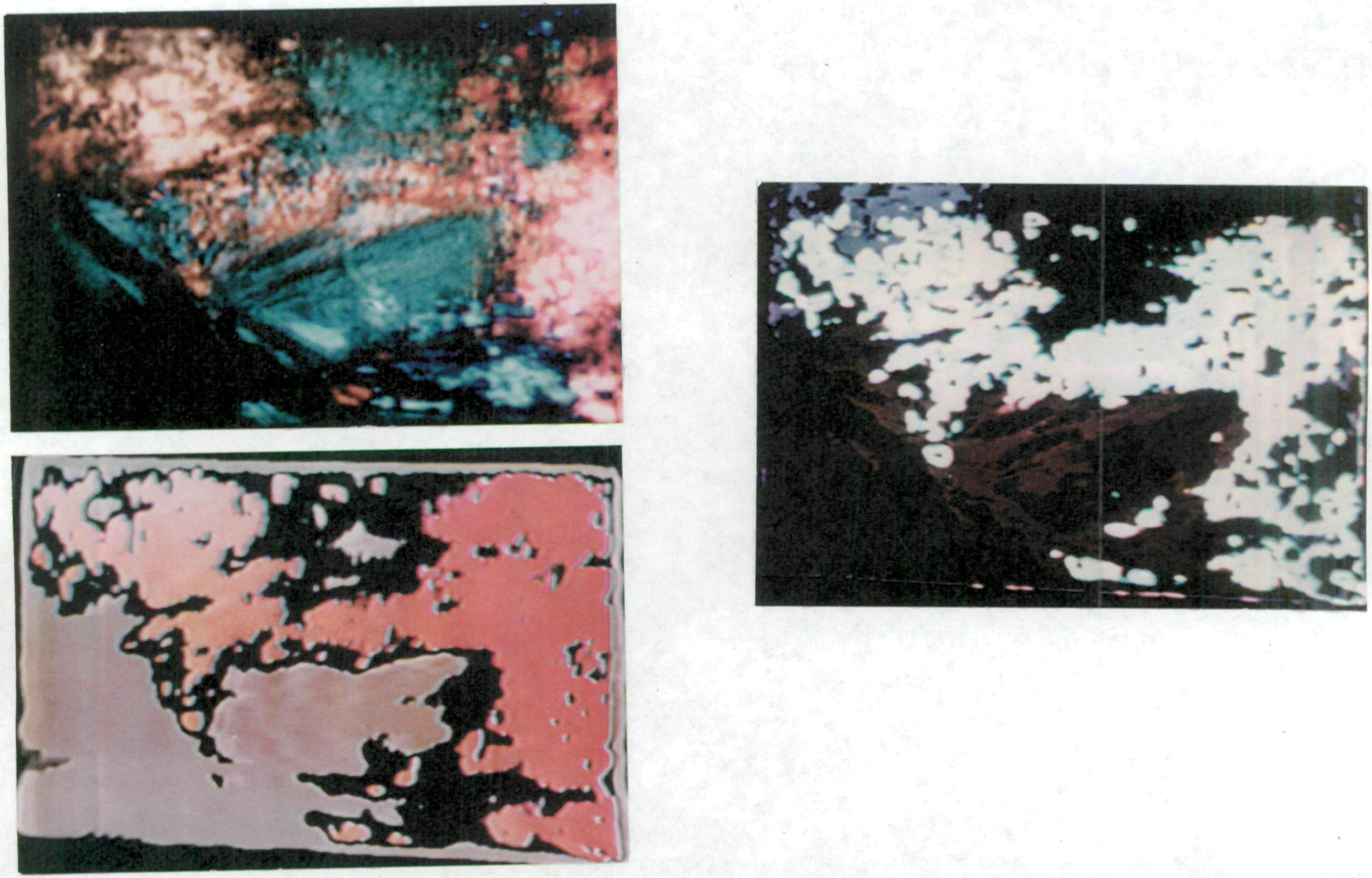


Figure 2.14. Color composites made by the IDECS (Image Discrimination Enhancement Combinations and Sampling) system located at CRES (Center for Research and Engineering Sciences) at the Univ. of Kansas. These composites, made from enlarged black and white space photos from the SO 65 expt., show the same area as seen in figure 2.11. The reader will note that the gross color schemes here coincide with the gross land use patterns. Quantitative evaluations will be made to determine the number of significant discriminations which can be made using these enhancement techniques.

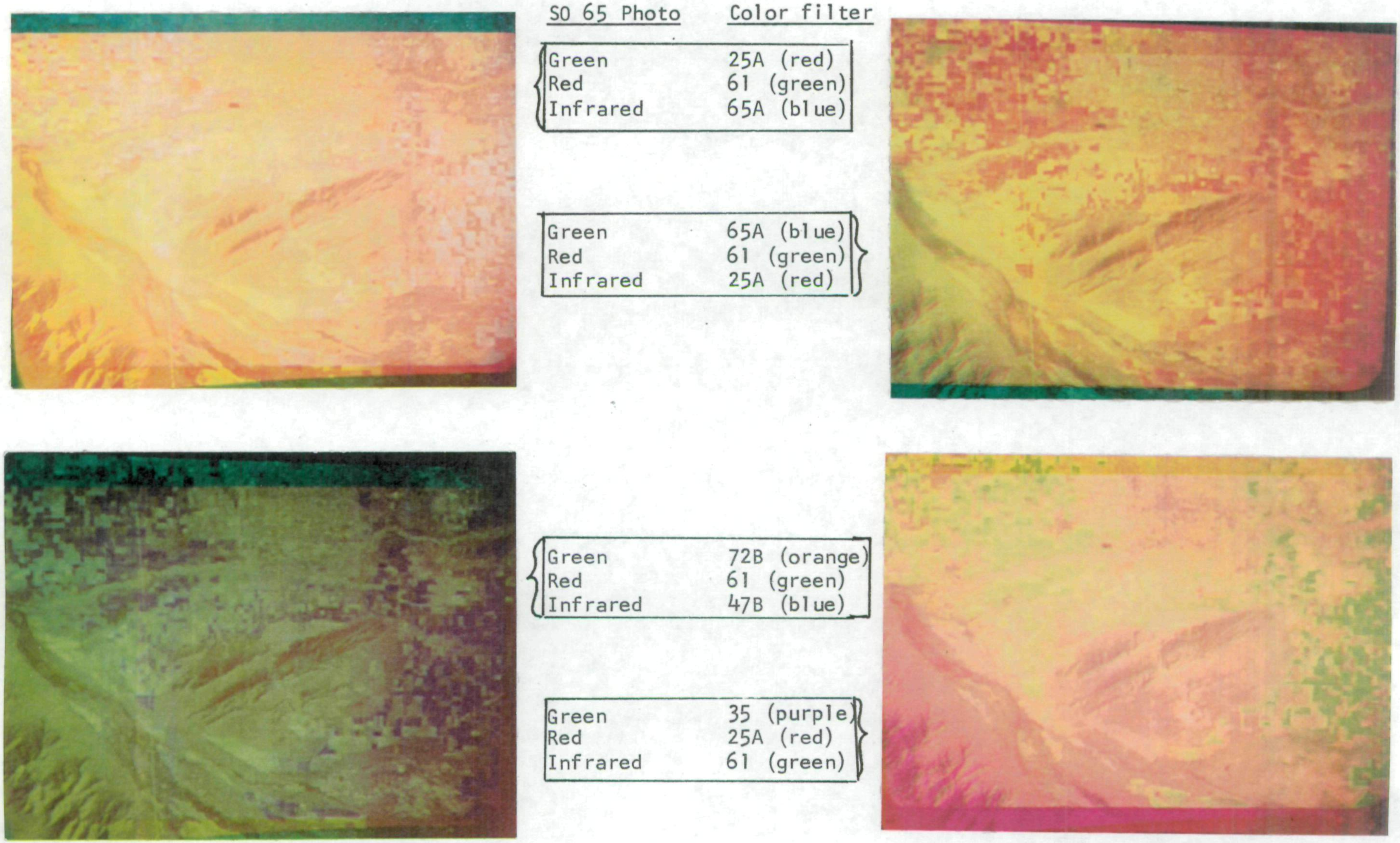


Figure 2.15. These optically combined color composites show the same area as seen on the space photo in figure 2.11, and were produced by projecting the three black and white SO 65 positive transparencies (green, red, and infrared) onto a screen in common register through various colored filters. The examples above illustrate only a few of the many possible enhancements that can be made with the projection system at the University of California. Subjective comparisons of the interpretability of each image can be made by the reader. More extensive quantitative evaluations to determine which color combinations are most interpretable will be made.

Figure 2.16 Reproduced here is an enlargement (Approximately 14X) from the original Infrared Ektachrome transparency, which shows the major agricultural features common to the Mesa-Phoenix area. Individual fields can easily be resolved due to their regular shape and field areas can be determined. The square area outlined measures 4 miles on a side and the representative dark field within it (see arrow) is 40 acres in area. The position from which the aerial oblique photo seen in Fig. 2.17 was taken is indicated above. This large area of citrus groves can easily be recognized by its brownish-red color. All of the other important agricultural crops appear within the outlined area. Continuous cover crops (wheat, barley, alfalfa and sugar beets) have a red color indicative of high infrared reflectance, but each type cannot be consistently identified from the others. Cultivated soil being prepared for planting appears dark in tone, while light areas usually contain buildings or other types of development. Each field in the area outlined above is identified on the accompanying map and oblique photo (Fig. 2.18 and Fig. 2.19). Note also the sharp boundary between developed and undeveloped (wildland) areas.

Figure 2.17 Infrared Ektachrome aerial oblique photo looking due east toward a large citrus producing area located east of Mesa, Arizona. The position in which this photo was taken and the corresponding area seen on the space photo is indicated in Figure 2.16. Citrus groves (oranges, grapefruit and lemons) have a characteristic rust color on the color infrared space photo and hence can be differentiated from the other crops in the area. Tests to determine the area occupied by citrus will be performed using photo interpretation techniques.

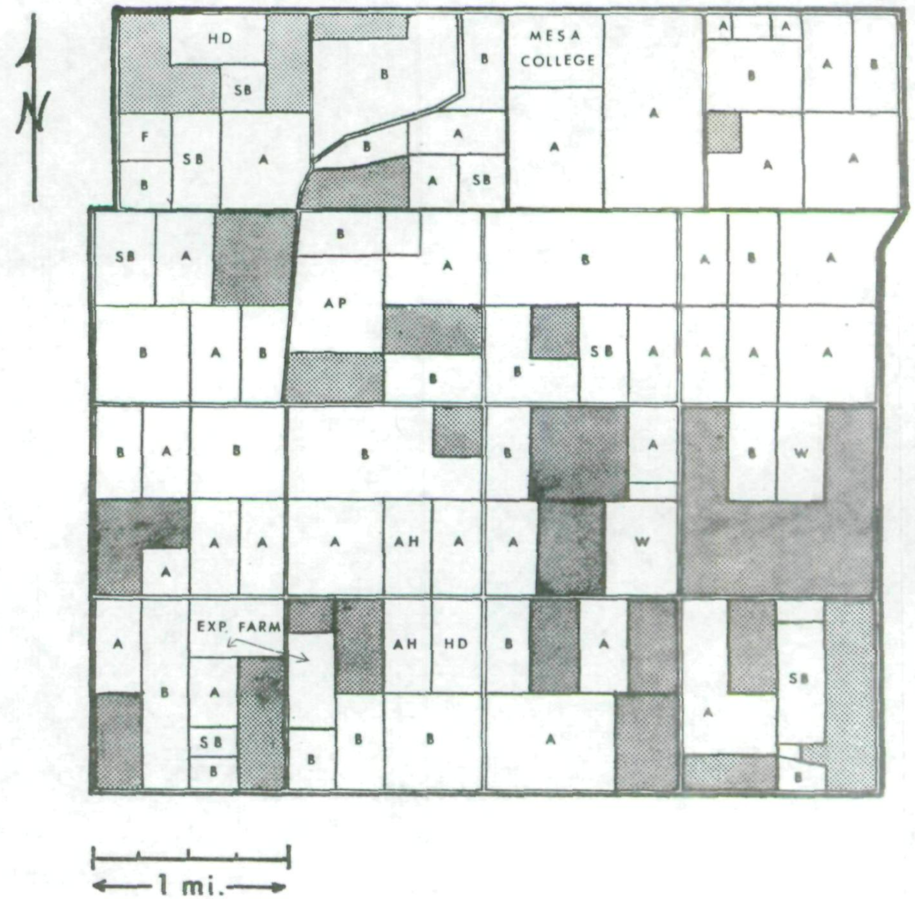


Figure 2.18 This diagram identifies agricultural crops and associated features within a 16 sq. mi. area (4 miles by 4 miles) located just south of Mesa, Arizona. An outline of this same area can be seen on the enlarged Infrared Ektachrome space photo in Figure 2.16. The reader is encouraged to locate a few fields to convince himself that agricultural crops can be mapped, despite the difficulty of correctly distinguishing between crop types. The dark gray to black areas are recently cultivated soils that are dark reddish brown. The planted crop types that appear reddish include: A, alfalfa; AH, alfalfa hay (i.e., alfalfa plus cereal grasses); AP, alfalfa pasture; B, barley, F, fallow ground with weeds; SB, sugar beets; W, wheat. Housing development is indicated by HD. Careful study of the crop types reveals that the variability of colors for any given crop, due to its age, density, plant spacing, etc., do not permit accurate differentiation of the aforementioned crop types on this kind of photography. There is good prospect that such distinctions will be possible, however, using the various techniques described in Chapter I for correlating the multiband black-and-white photos obtained from Apollo 9 in the S065 experiment. Such feasibility studies are presently underway.

Figure 2.19 Infrared Ektachrome aerial oblique photo showing representative crop types and cultivation patterns. The crops identified in this photo occur within a 16 sq. mi. study area (4 miles x 4 miles) located just south of Mesa, Arizona. The position of the large study area and the position of this photo with respect to the study area is indicated on the space photo in Fig. 2.16. Note that on this photo, as well as in the space photo, the important crop types cannot consistently be differentiated. Crops seen on this photo include: A, alfalfa; AH, alfalfa hay; B, barley; SB, sugar beets; and W, wheat.

Fig. 2.20. This is a 7X enlargement of an Infrared Ektachrome space photo of the Roosevelt Lake area, east of Phoenix. Arrows point to several of the most important natural resources of the area. The snow pack can be delineated easily (due to the contrast of its white color with the darker background) and differentiated from scattered clouds which are generally distinguished by their shadows. The bodies of water outlined above provide water storage and flood control as well as popular water sports activities, and can easily be identified by their uniform dark tones. The development of important mineral resources at Miami and Globe can be detected by the light toned areas which are open-pit copper mines and accompanying tailing piles. The dark objects in this mineralized area are tailing ponds containing waste water from the mining operation. Wispy trails of smoke from copper smelters at both Miami and Superior can also be seen on this space photo. The various shades of lavender or red on this photograph are indicative of the many types of vegetation found in such wildland areas as this, and include semi-desert shrub (at lower elevations), chaparral, oak woodland and Ponderosa pine types. The ability to delineate each of these types accurately in a resource survey is one of the major objectives of the present study and will be reported upon in highly quantitative terms in a subsequent report.

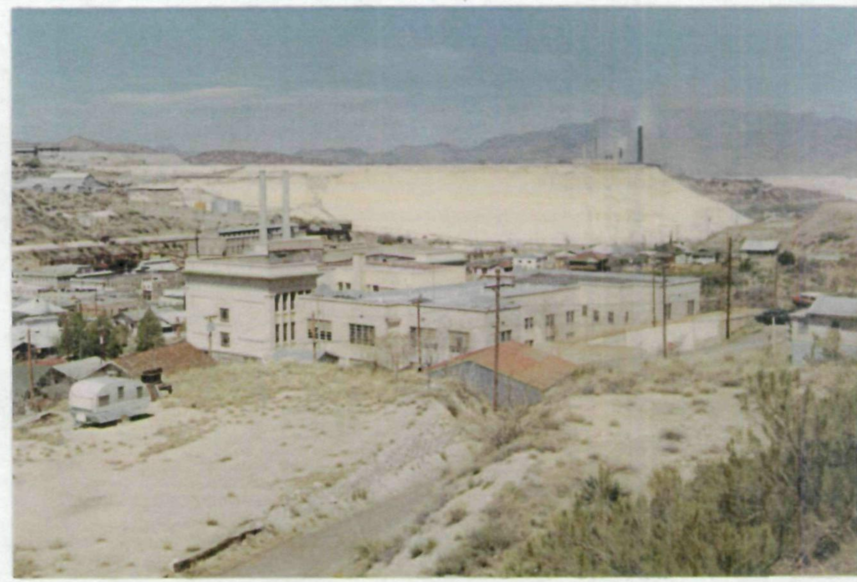
Sediment ladened water from Tonto Creek entering Roosevelt Lake

Figure 2.21 The top two photos (color and Infrared Ektachrome) show Tonto Creek ladened with sediment emptying into Roosevelt Lake. Note that on the space photo in Fig. 2.20, sediment ladened water appears blue relative to the clear water which appears black. Note that much sediment is also entering from the southeast end of the lake. The bottom two photos show a major contact between granite and dacite (center), a flow material of volcanic origin. The dacite flow is quite conspicuous on the space photo in Fig. 2.20, due to the apparent scarcity of vegetation which can be supported on this geologic formation, in contrast to the greater amount of semi-desert scrub vegetation formed on the granite. Apache Lake appears on the right.

Canyon Lake - Water Storage and Recreation

Four Peaks - Timber species covered by snow

Undulating topography covered by semi-desert shrub vegetation. Four Peaks in background.



Copper ore tailings pile and smelter in Miami, Arizona.

Fig. 2.22. These photographs show some of the land use activities and vegetation types encountered in the wildland area seen in Figure 2.20. Further analysis of the space photo in Fig. 2.20 will seek to determine how accurately one can discriminate the broad natural vegetation types which occur in this area.

CHAPTER III

ANALYSIS OF RANGE RESOURCES IN THE TOMBSTONE, ARIZONA AREA

by

Barry J. Schrumpf*

The accuracy of small scale rangeland resource maps using space photography depends on the kind and quality of photograph, the photo interpreter's knowledge of range vegetation units that reflect the ecology of the landscape, and his ability to interpret the photograph in terms of these units or combinations of them. Convergent evidence, such as drainage patterns, soil color, aspect and elevation must be evident, as well as color or tone changes due directly to vegetation changes.

Three Apollo 9 space photographs are used here to demonstrate important uses of different film and filter combinations for producing a native vegetation map and for recording changes occurring in a range area. Although the major portion of the area shown had cloud cover at the time of photography, the cloud-free portion includes approximately 4,000 square miles, and many more square miles are visible through the scattered cloud cover. The film types are Infrared Ektachrome, Ektachrome and Panchromatic filtered with a Wratten 25A filter to expose for red wavelengths of light.

Features are pointed out on the film type where they are judged to be best represented. The reader is encouraged to compare the same feature on the other space pictures.

* Temporarily assigned to the Forestry Remote Sensing Laboratory from the Department of Range Management, Oregon State University.

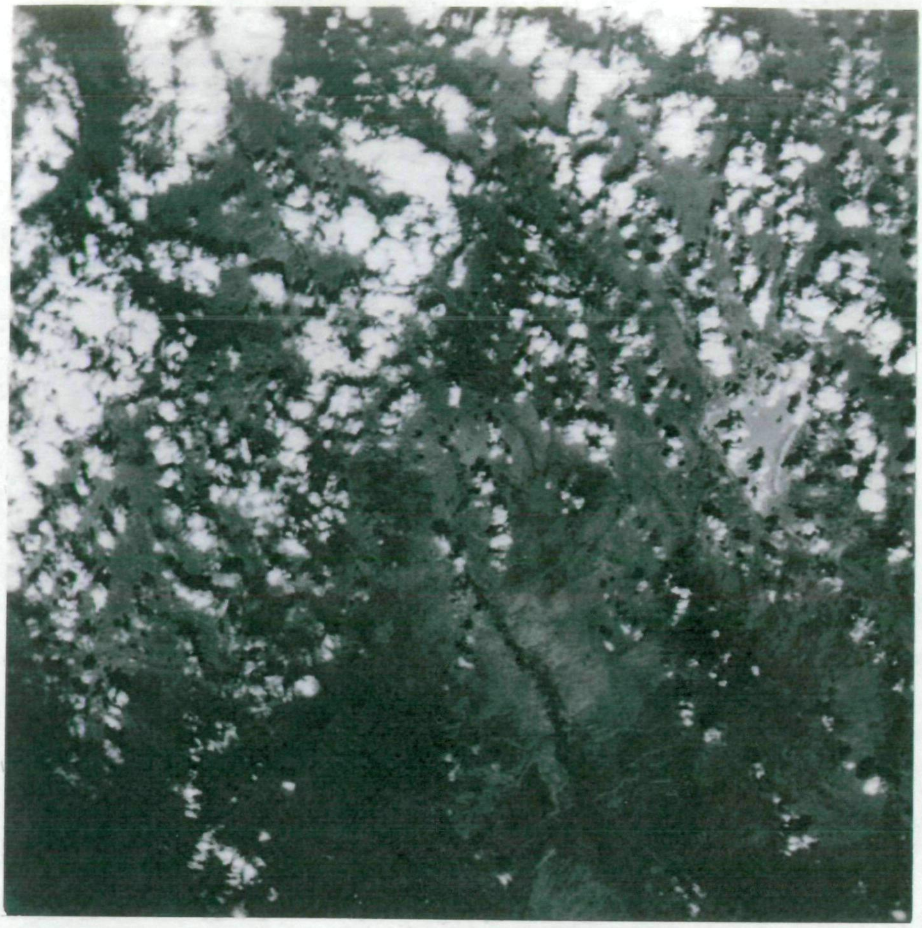


Figure 3.1 Apollo 9 photo AS-9-26D-3751 exposing for red light. Since the longer wavelengths of visible light are recorded by this film and filter combination, there is less scattering by atmospheric haze. Consequently, sensing in this band of the spectrum can be expected to improve resolution capabilities. This factor relates not only to the job of the photo interpreter, but also very importantly to the logistics involved in collecting ground truth at representative locations.

Figure 3.2 An enlargement of a portion of Apollo 9 photo AS-9-26D-3751. This 7X enlargement shows much of the road detail around Tombstone, Arizona. Both hardtop and graded dirt roads are easily located making it possible to choose the best approaches to ground locations within areas represented by distinct photo images. This can save many man-days when such tremendous areas are involved.

The quality of this picture reveals in area 3.2-A a very fine pattern of drainage channels which extend roughly parallel directly downslope.

Figure 3.3 Ektacolor oblique photo. This low oblique photograph shows the fine drainage pattern noted on the space photograph. This pattern is typical of arid and semiarid areas that receive large volumes of water in short periods of time during thunder storms. Most of the precipitation is lost as surface runoff; very little infiltrates the soil. This is due to the slope, soil texture and the vegetation cover. The channels support shrubs and some perennial bunchgrasses. The uplands between them have scattered shrubs and half-shrubs, a few species of cacti and a relatively poor grass cover.

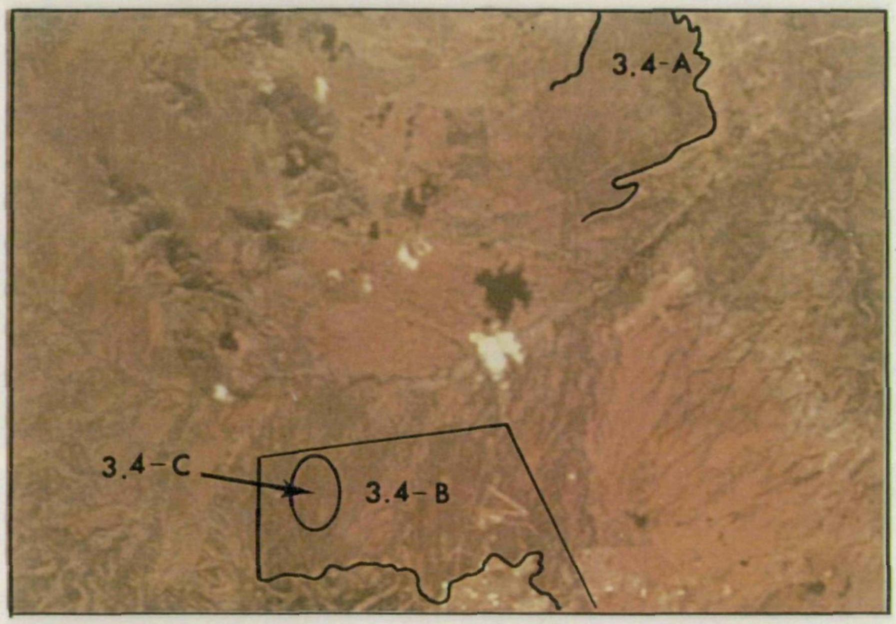


Figure 3.4 Ektachrome Apollo 9 photo AS-9-21-3306 (8X enlargement). Several images on this picture are meaningful to the range manager. A flat, slightly sloping area (3.4-A) supports a dense cover of mixed desert shrubs (see illustration 3.5). The fenced area at 3.4-B has not been grazed for many years leaving a heavy grass cover that produces a darker image on the photograph. The dry grass stalks and leaves provide ready fuel for range fires. A recently burned area is detectable at 3.4-C (see also illustration 3.6).

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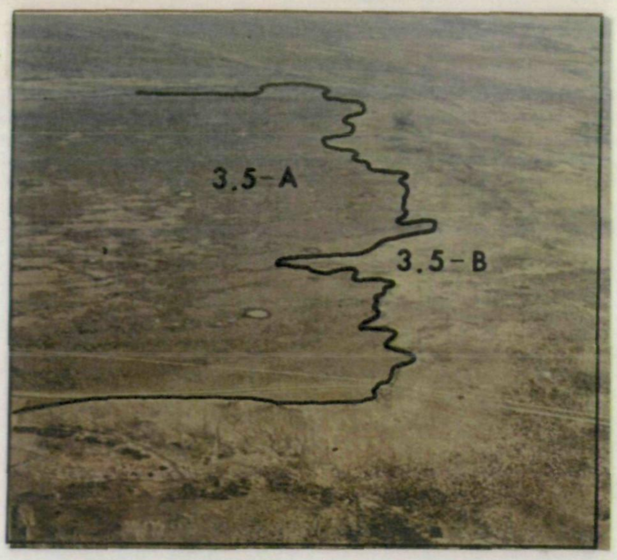


Figure 3.5 Ektacolor olbique photo. The dark image at 3.5-A is the area supporting a dense cover of mixed desert shrubs. There is little grass production within this area. The white soil area at 3.5-B is being subjected to active erosion and supports considerably less shrub cover.

Figure 3.6 Ektacolor oblique photo. The dark reddish-brown area was burned during the fall of 1968. This low oblique was taken the same week as Apollo photo 3.4. The dried grass material was removed by fire leaving the soil surface exposed to view.

Figure 3.7 Infrared Ektachrome Apollo 9 photo AS-9-26A-3751. Infrared reflectance, registering red on this film, reveals the location of plants having healthy green foliage during the second week of March, 1969 when the photograph was taken. This relates to plant phenology and therefore facilitates photo interpretation after prior knowledge has been gained of the phenologies of the various vegetation units involved. At this time of year, only the evergreen species show red in the photograph. These are species primarily constituting the chaparral, juniper-oak woodland, and pine forests vegetation units. This space photograph therefore helps to distinguish the upper limits of the desert grassland because the grasses have not begun production of new green leaves, whereas the evergreen species at slightly higher elevations appear red (3.7-A). This is a distinction not accomplished on the other film types.

Figure 3.8 Infrared Ektachrome oblique photo. Evergreen oaks and junipers blanket many of the high slopes of these mountains (see also 3.7-A). These plants also grow at the lower elevations in stream channels. The oaks extend down out of the mountains into the grasslands within the stream channels where their size and depth provide protected environments. Infrared photography taken at the end of April would help to distinguish the lower elevation boundaries of the desert grasslands, because the deciduous desert shrubs would have leafed out in response to the warming temperatures following the winter rains. The perennial grasses do not begin growing until after the summer rains of late July and early August. The strong infrared reflectance of the grass during late August would show the extent of the desert grassland, and also the extent of good grass understory cover within areas previously identified as desert shrub.

Figure 3.9 Ektacolor oblique photo. This illustration pictures an ecotone between desert shrub (3.9-A) and desert grassland (3.9-B). Ektachrome infrared space photography best depicted this same change (see 3.7-B).

CHAPTER IV

ANALYSIS OF EARTH RESOURCES IN THE VICKSBURG, MISSISSIPPI AREA

by

Edwin H. Roberts

Preliminary investigation of S065 photography centered on Vicksburg, Mississippi, and covering a swath extending from the vicinity of Monore, Louisiana on the west to Jackson, Mississippi on the east, suggests that at least the following broad land classification categories may be consistently identifiable on space photography (multiband black-and-white) at this season of year: (1) deciduous hardwood, (2) deciduous hardwood in standing water, (3) pine forest, (4) cultivated land, (5) open bodies of water such as lakes and reservoirs, (6) rivers and canals, (7) urban areas, and (8) major roads. It may be possible to further divide cultivated land into types of agriculture, but at the time of writing this report insufficient work has been done to evaluate that aspect.

In order to document the ground conditions in this region, vertical and oblique aerial photography with Ektacolor and Infrared Ektachrome films was obtained within two weeks after the flight of Apollo 9. Such documentation is essential in the study of an area such as this one which undergoes dramatic seasonal change. Without such supporting photography it would be impossible to establish the phenological state of the vegetation at the time when the space photographs were taken and the condition or state of other features.

The following pages show examples of the S065 multiband photography and supporting vertical and oblique aircraft photography of small areas representative of this part of the country.

Figure 4.1 Shown here is a two diameter enlargement from one of the photographs acquired by the S065 experiment aboard Apollo 9. This photograph was taken on Ektachrome Infrared Aerial film, commonly called color infrared, which is sensitive to green, red and infrared radiation. The area shown is about 100 miles on a side with the Mississippi River at the extreme right. U. S. Highway 80 (Interstate 20) crosses in an east-west direction in the lower part of the photograph. The area seen is mostly in Louisiana, with the Arkansas border near the top. Several water bodies are seen varying in tone from inky black to blue, depending on the turbidity of the water. The wide light swath running north-south on the right part of the photograph is agricultural land on a former floodplain of the Mississippi River. The dark blocks within this are uncut patches of hardwood. A large area of hardwood forest with agriculture in its center can be seen in the lower right corner of the photo.

Figure 4.2 This photograph from the S065 experiment is a 4X enlargement from the original size. The area shown extends from the Mississippi River in the vicinity of Vicksburg west about 100 miles past Monroe, Louisiana. It was exposed in the red part of the spectrum. Enlargements within the outlined areas A, B and C are shown in subsequent illustrations.

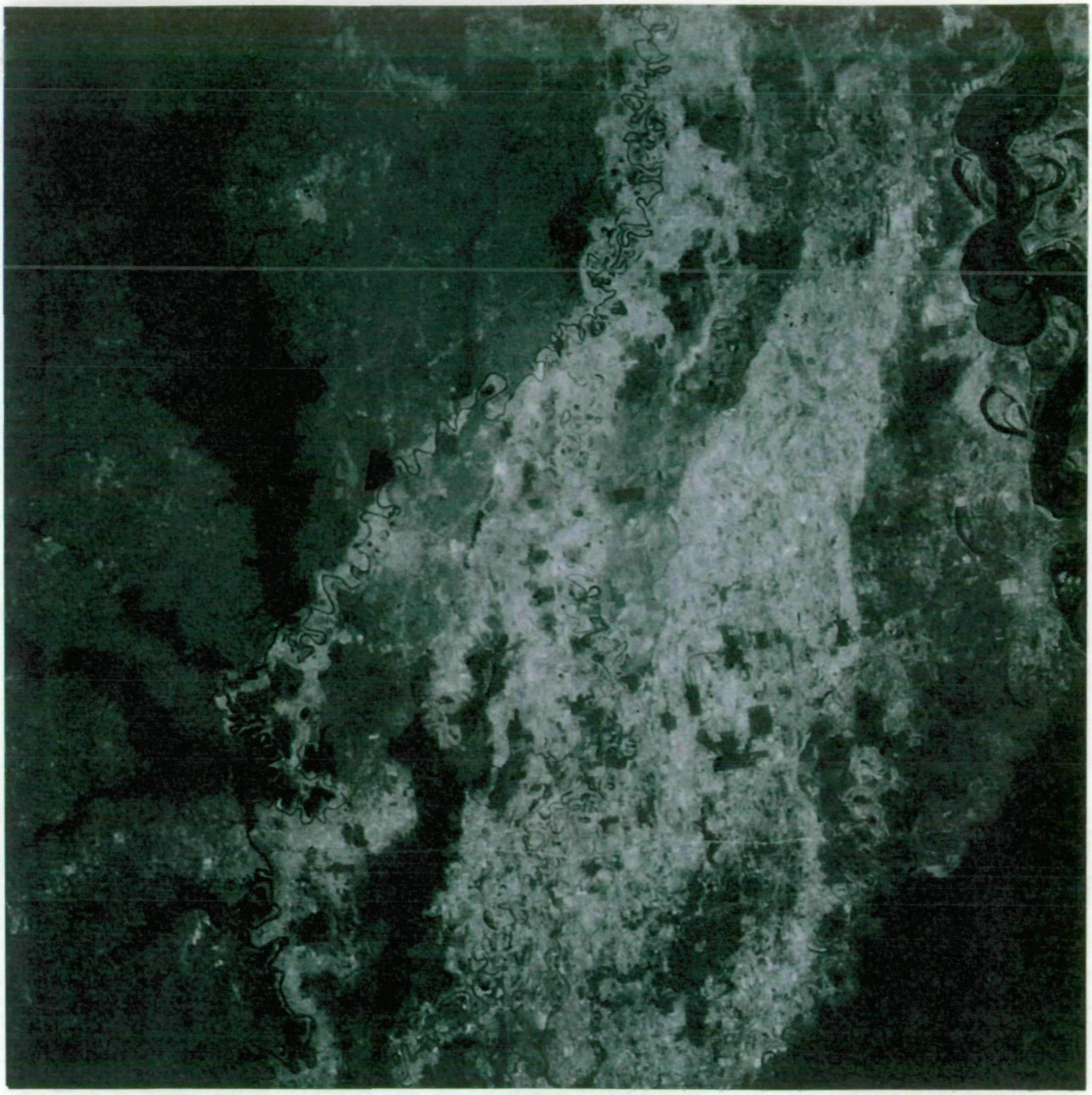


Figure 4.3 The area shown in Figure 4.1 is seen here as photographed by using the infrared part of the spectrum. Water surfaces appear black on infrared photography and are easily mapped. Healthy crops and the bare soil of agricultural fields not yet covered by growing crops show as light-toned areas while deciduous hardwood forest is intermediate in tone.

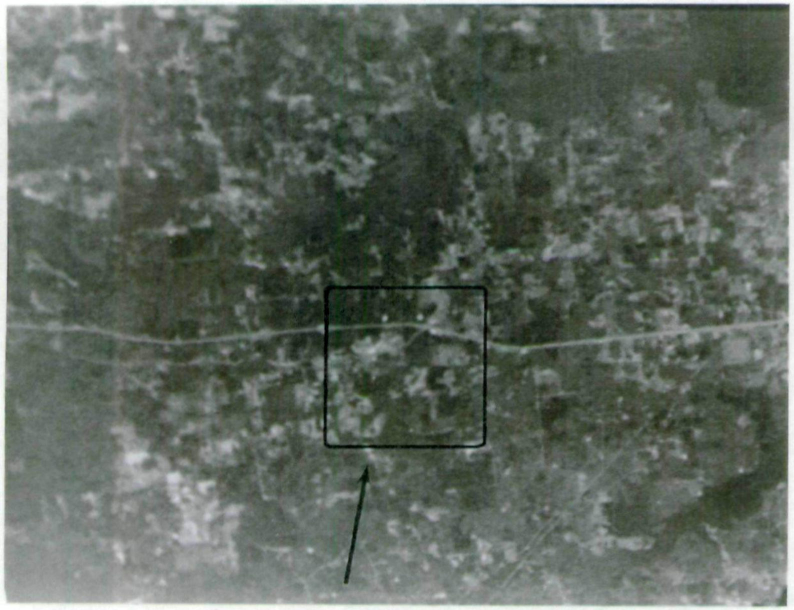


Figure 4.4 A $2\frac{1}{2}$ X enlargement of area A from Figure 4.2 (10X from the original) is shown at the left. The outlined area is seen at a scale of 1/45,000 on the vertical aerial photograph at the right taken from an aircraft flying at an altitude of 20,000 feet. By using aircraft photography to identify ground conditions and features in a sample of the area, it is possible to begin establishing tone patterns for these features on the S065 multiband photography. In this example it can be seen that on the S065 photography the cultivated fields are consistently light in tone. Pine forest and water are consistently dark in tone while deciduous hardwood is intermediate. It may be noted that these responses are like those recorded on infrared film for these features; however, as the crops form a ground cover on the cultibated fields the light tone recorded from the red part of the spectrum will give way to a dark tone, while these fields will remain light in tone as recorded in the infrared part of the spectrum.

Figure 4.5 This oblique color infrared photograph was taken from approximately 2,500 feet altitude. It is centered on the area shown in the previous illustrations, and was taken from the direction indicated by the arrow on the left photograph of Fig. 4.4. This type of photography is aptly suited to documenting the features and their condition at the time of the S065 experiment. On this photograph the important distinction is easily made between pine forest which appears magneta and deciduous hardwood which appears bluish. This distinction can also be made to a good, but as yet undetermined accuracy from enlarged S065 photography.

Figure 4.6 This 10X enlargement over the original scale of S065 photography shows the scene within the area marked B in Figure 4.2. It is included primarily to show the good detail observable from the present space photography. The street pattern of the city of Monroe, Louisiana, which dominates this view, is clearly discernible. The transportation arteries into the town can be identified; as can the Ouachita River flowing through the town. The pattern of small white spots in the center of the photo are individual water plumes from the town's water purification plant. Three large light areas at the lower left are large gravel pits; above these can be seen the dark surface of Cheniere Brake Reservoir. At the upper right the runways, taxiways and terminal building of the Monroe Airport can be seen. It should be emphasized that all the S065 photographs shown in this report are reproductions made from duplicates of the originals and cannot show the detail present in the original photography.

Figure 4.7 On the left is shown an enlargement of the area within C as marked on Figure 4.2. The photograph on the right is an oblique view from 2,500 feet altitude using color infrared film. It is easily recognized as showing the same central area as the left photo by reference to the converging roads and the canal crossing at right angles to them. The swampy nature of the terrain in this area can be inferred even from the space photograph by noting the many water-filled borrow pits from which roadbed materials were taken in order to build a raised roadway which is abovethe general level of the terrain. Notice that the water in the canal and in some of the borrow pits is turbid and is light in tone on both photographs while clear water is dark in tone since very little radiation from these features is reflected in the spectral bands to which these films are sensitive. Although the deciduous hardwood forest dominating this area is composed of many different species of trees, it presents a relatively uniform and unique tone and color response on the S065 imagery and appears to be consistently identifiable.

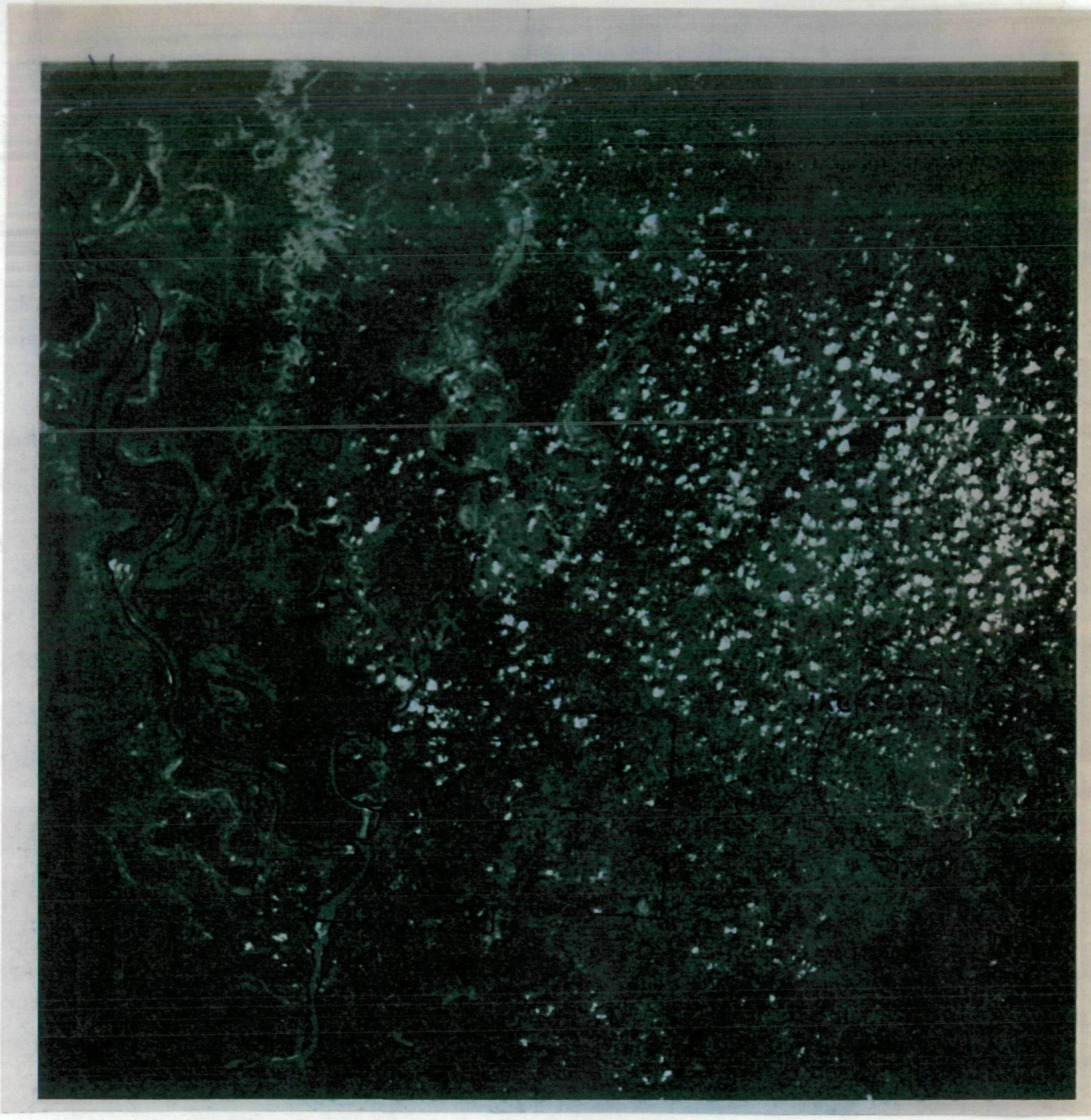


Figure 4.8 The S065 photograph shown here was sensitive to radiation in the red part of the spectrum, i.e., it was taken using a 25A filter and panchromatic film with extended red sensitivity. The area seen extends from the Mississippi River on the west to a point a few miles east of Jackson, Mississippi. The area seen here and on the following photograph is east of, and contiguous with, the area shown in Figures 4.1, 4.2 and 4.3. Enlargements of the areas outlined as D and E are shown in illustrations which follow. Differing degrees of turbidity between the Mississippi River and the still clear water in the oxbow lakes adjacent to the present course of the river can be seen.

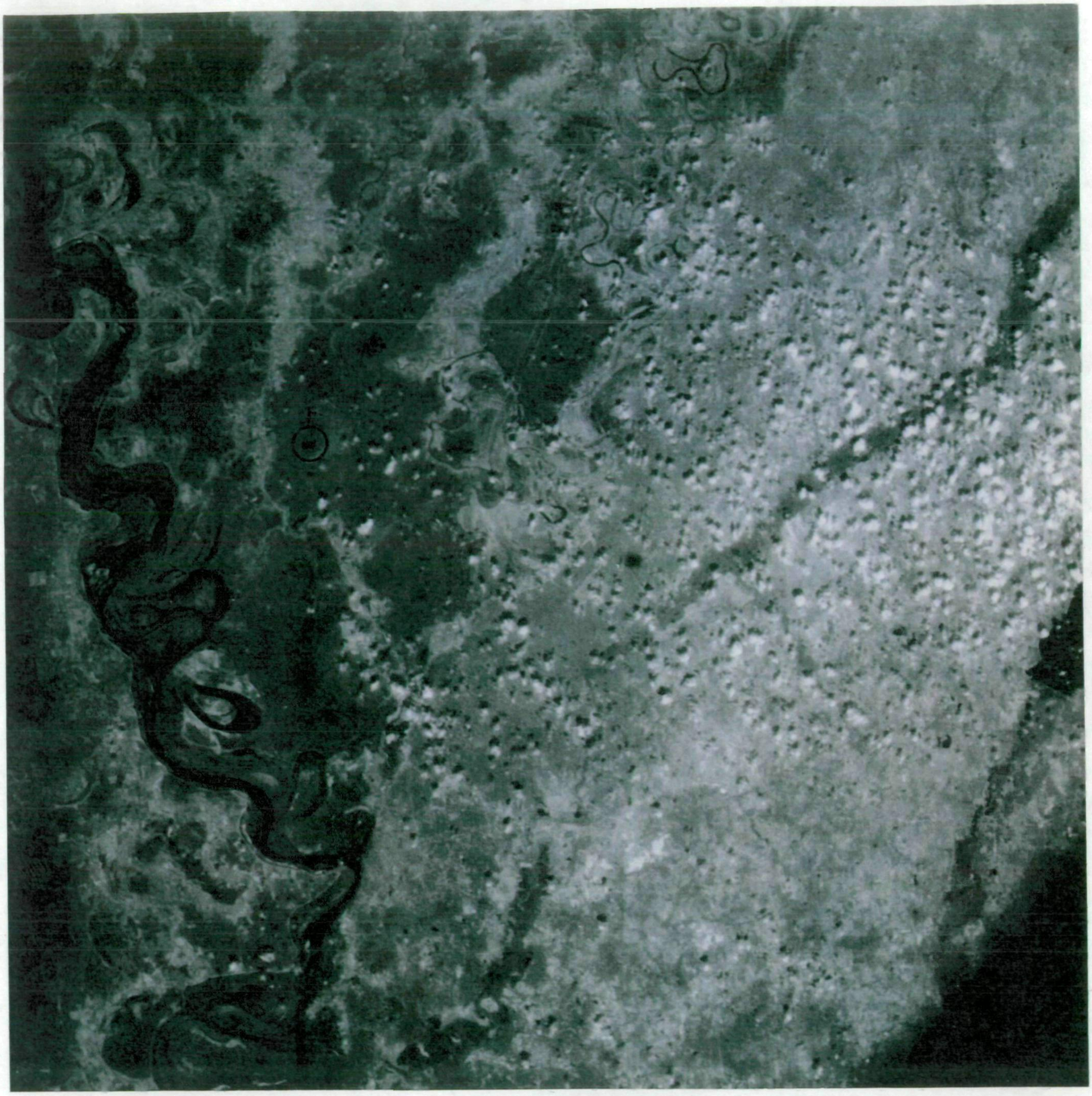


Figure 4.9 Shown here is the area seen in the previous illustration, but taken with a film and filter combination resulting in net sensitivity to only the near-infrared part of the spectrum. Clear water appears black and is easily delineated, but very muddy water gives almost the same reflectance as bare soil and the two may be nearly indistinguishable. For example, the course of the very muddy Yazoo River is difficult to trace on this photo. It is easily followed on the previous illustration because of the relatively high red reflectance of the suspended sediment. Conversely, the rectangular area of open water circled at F on this photograph is easily seen, but this feature can not be seen on the previous photograph.

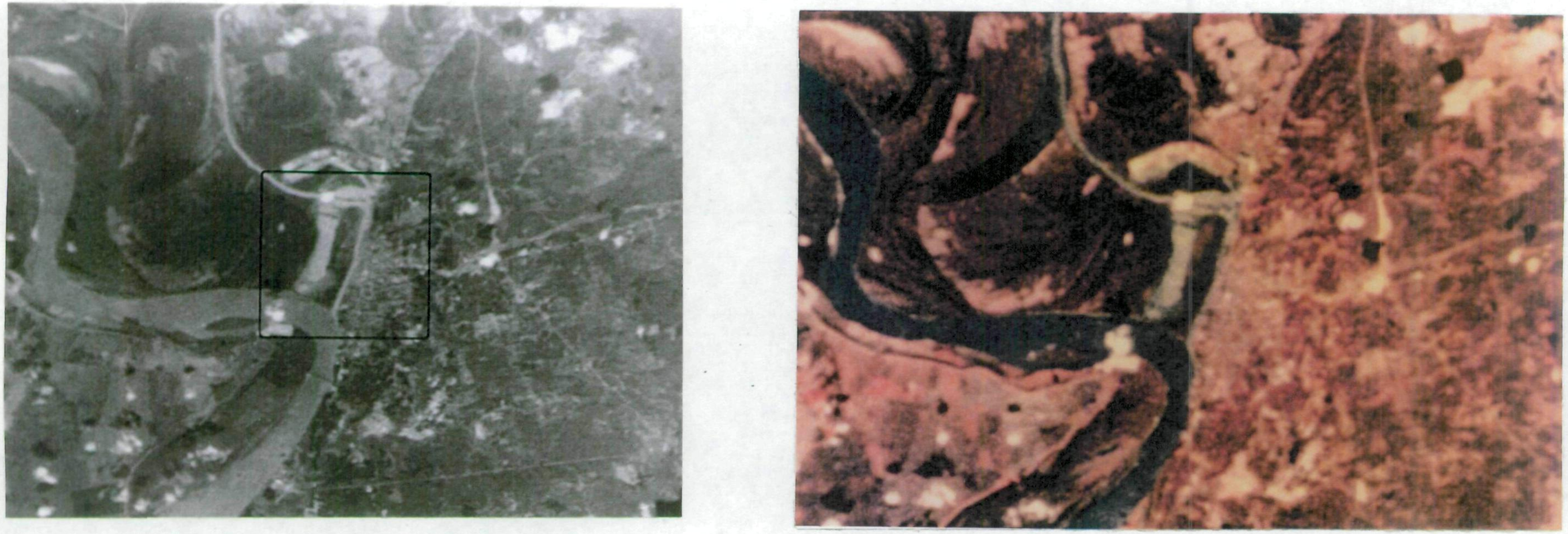


Figure 4.10 Shown here are enlargements of S065 photography from the area outlined at D on Figure 4.8. The left photograph was enlarged from the red sensitive film-filter combination and the right photograph from the color infrared film. The centers of the photographs show the confluence of the Mississippi and Yazoo Rivers at the city of Vicksburg, Mississippi. The oblique and vertical aircraft photographs which follow give a closer view of this outlined area. The interface between the very muddy Yazoo River and the comparatively clear Mississippi River is evident for several miles downstream before the mixing action blends the two. Old meander scars made by the river are evident because of vegetation density differences and water filled depressions. Much of the wandering of the Mississippi River through recent geological times is evidenced on space photography by these meander traces and oxbow lakes.

Figure 4.11 The Yazoo River at Vicksburg, Mississippi is seen here as photographed from an altitude of 20,000 feet. Note that many of the vegetation patterns seen here are also discernible from space photography.

Figure 4.12 The difference in the degree of turbidity between the Mississippi River and the Yazoo River entering it here at Vicksburg is dramatically portrayed by this oblique photograph taken from an altitude of 2,500 feet.

Figure 4.13 The confluence of the Mississippi River and the Yazoo River at Vicksburg, Mississippi is shown here on color infrared film as exposed from 20,000 feet altitude. The condition of natural features is well documented by this photograph, one of a continuous series flown between Jackson, Mississippi and Monroe, Louisiana, shortly after the flight of Apollo 9. Three degrees of water turbidity can be recognized; the most turbid water is very light, or milky blue, while the clearest water is dark blue. Healthy foliose vegetation is pinkish while that not yet leafed out is purplish-blue. Standing water can be seen within some of the deciduous forest areas.

Figure 4.14 This oblique color infrared photography taken from an altitude of 2,500 feet looks up the Mississippi River from below the bridge crossing at Vicksburg. Even in the foreground of this picture, which is about 5 miles downstream from the point it empties into the Mississippi, evidence of the turbid water emanating from the Yazoo River can be seen. Windrows from recently cleared hardwood forest are visible beyond the west bank of the Mississippi River. Although the cleared area is visible on space photography, the fact that is was recently cleared is not. However, clearing operations such as this could be easily observed on sequential imagery obtained from orbiting platforms.

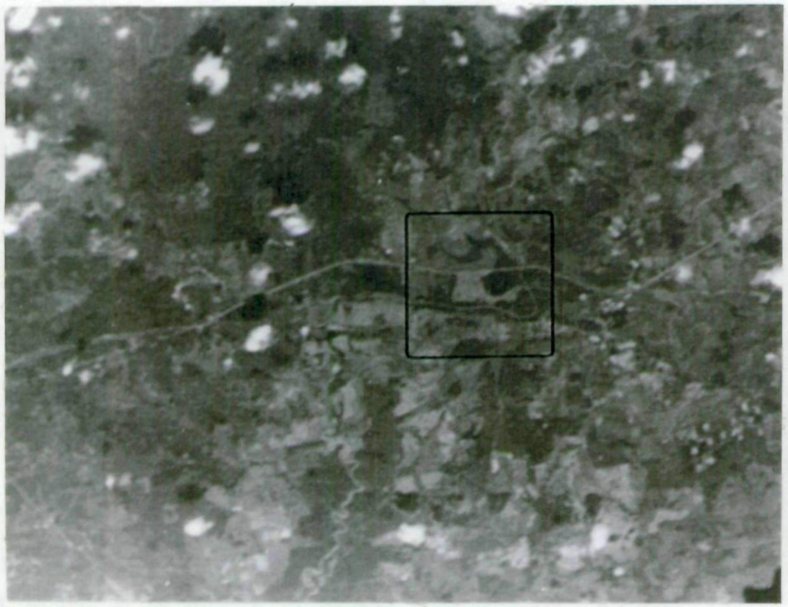


Figure 4.15 The two photographs above are enlargements from S065 photography and show the area outlined at E in Figure 4.8. The one at the left is from the red sensitive film-filter combination and the one on the right from color infrared film. The area outlined on the left photo is shown in the following illustration. This is an area characterized by gently undulating terrain. A patchwork of agricultural fields (mostly pasture) and upland hardwood forest covers the terrain. The two are easily separated in this region on S065 photography. Swampy hardwood areas can be identified by their very dark tone and the fact that there are usually drainage features leading into them. On these photographs it is important to be aware of cloud shadows so as not to confuse them with wet areas.

Figure 4.16 The area outlined on Figure 4.15 is shown here as photographed with color infrared film from an altitude of 20,000 feet. The patchwork of agricultural fields can be seen. Fields which have been cultivated, but do not yet have an emerging plant cover, appear light blue. With increasing degrees of plant cover the fields show as light pink and then red. Interstate Highway 20 crosses the photograph from left to right. The Big Black River enters from the north then makes a sweeping turn to the west. Its course is outlined by a stringer of hardwoods. A swampy area just below the highway and to the west of the river is identified by its very dark tone and the light blue of a water surface showing through the trees.

CHAPTER V

POSSIBILITIES FOR AUTOMATED ANALYSIS

by

Jerry D. Lent

At the time of this writing two kinds of data obtained in connection with the Apollo 9 S065 experiment are being subjected to automatic analysis. These are (1) the three types of multiband black-and-white photography obtained both from the spacecraft and from supporting aircraft, and (2) the many bands of sensing data that were recorded in analogue form through use of optical mechanical scanners operated from the supporting aircraft.

Theoretically, the collecting of target signatures in several wavelength bands by either of these means should provide a unique set of signatures for each type of earth resource feature or terrain condition. However, the signature differences may be extremely subtle so that <u>mechanical</u> rather than <u>human</u> interpretation is necessary.

Figure 5.1 shows enlarged copy prints of the Tucson-Willcox-Ft. Huachuca test area as seen on Apollo 9 Frame #3751, which was taken at about mid-day (local time) March 9, 1969. It shows considerable cloudiness which obscures certain specific areas of interest. The acetate overlay denotes (a) key reference points within the field of view, (b) areas where the Bendix multichannel scanner obtained usable imagery, and (c) the multidisciplinary aspects of features present in the region. Density measurements of the original negatives for this frame exhibited maximum densities of approximately 1.56 and a film process gamma of 1.40. Subsequent generations of copies (such as the one from which Figure 5.1 was derived) had similar maximum densities but a somewhat lower processing

gamma. It is important to know these parameters when analytical techniques are to be applied to existing film data sources. For target signature determination, these values determine the dynamic range of possible grey levels with which features within the field of view can be recorded.

When scanner data are considered, a different set of factors for target discrimination comes into play. The Bendix multichannel scanner, recording energy levels in eight distinct wavelength intervals, enables further refinement of target signature definition. However, the complexity of studying and categorizing eight separate signature levels necessitates the employment of computers. Target discrimination programs can be developed which will statistically categorize features of interest on the basis of their 8-dimensional data. The performance of such tasks is well within the capability of high-speed computers, even though the tasks are too complex for the human interpreter to resolve. Present work entails a study of eight-channel scanner data of selected areas where distinctive features are readily apparent and where complete "ground truth" was acquired during the time of data acquisition from Apollo 9 and from supporting aircraft. Several analytical techniques for handling and processing the analog data have been developed by Bendix personnel and previously tested using agricultural features. These techniques are (1) <u>Factor analysis</u>, where nearly 98% of the terrain reflectance variation was accounted for in three factors; (2) <u>Regression analysis</u>, for determining the linear coefficients of particular features of interest among the different channels of data for display purposes; and (3) <u>Discriminant analysis</u>, for comparing the responses of the features of interest in order to increase the statistical probability of correctly identifying them.

The illustrations appearing in this section show representative areas on which these various types of automated analysis are currently being performed.

Figure 5.2 shows a selected portion of Bendix scanner imagery in negative print form. Individual channels as well as combinations of channels are included on the following pages. The combining technique, as performed by Bendix, was done without any emphasis on one or more of the channels (that is to say, it was linear) since a thorough analysis of the data has not been completed thatwould enable an investigator to highlight any particular feature. Rather, these combinations are more in line with the energy levels exhibited by the black-and-white photographic images obtained from Apollo 9, matching fairly closely the respective wavelength intervals. The final combination of data is a summationof all channels. This particular piece of data, extracted from the coverage of the rangeland environment is presented to demonstrate the interpretability of a characteristic phenomenon that is indicative of terrain conditions. Specifically, differing animal management practices have caused a distinct change in vegetation composition on either side of the fence-line readily seen on some of the channels of data. In other channels, this characteristic difference is not nearly as apparent. Additive color combining techniques currently are being employed to enhance these subtle grey level differences to more interpretable color hues. Computer analysis of multichannel data can recognize and sort out more grey levels than the human eye, and thus afford a statistical decision-making capability that might facilitate the land manager's awesome interpretation task. Careful study of the original black-and-white Apollo 9 photographs reveals not only the presence of some fenceline boundaries but also other man-made marks on the landscape

which can be studied by automated means for management purposes.

Figure 5.1 Enlarged copy prints of the Tucson-Ft. Huachuca-Willcox (Arizona) test site area for S065. Considerable cloudiness is seen to obscure some of the areas of specific interest. The overlay denotes key reference points, areas where usable multichannel scanner data exists, and scientific features of interest for inventory or evaluation purposes, respectively (left to right). Methods of implementing such inventory and/or evaluation schemes are outlined in the text.

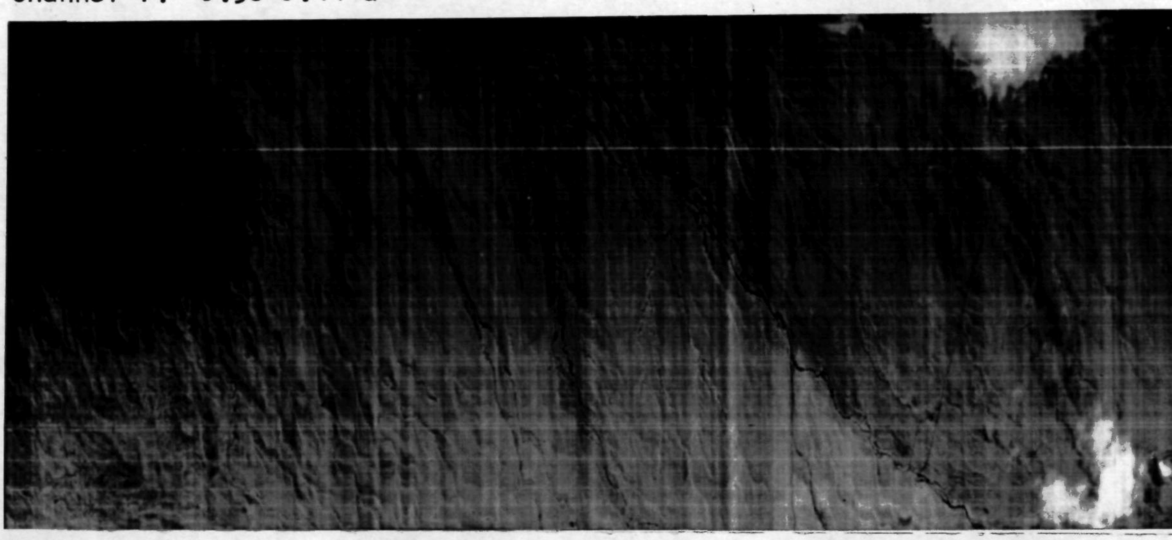
KEY REFERENCE POINTS — Frame 3751: Pan-58 (Green)

USABLE BENDIX COVERAGE — Frame 3751: Pan-25A (Red)

FEATURES OF INTEREST — Frame 3751: IR-89B (Photographic Infrared)

(a) (b) (c)

Channel 1: 0.38-0.44 u



Channel 2: 0.44-0.50u

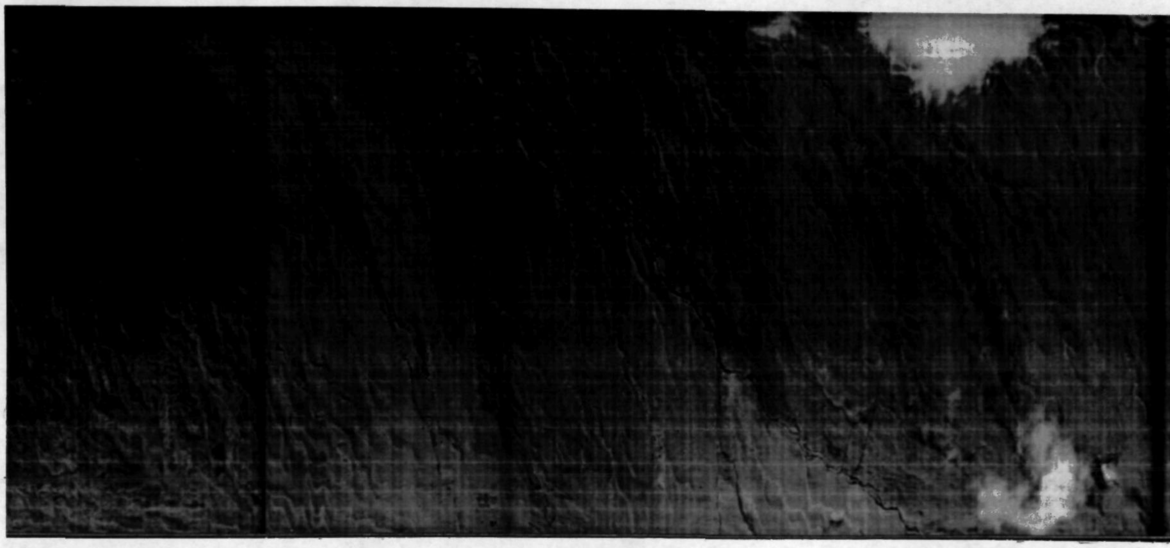


Figure 5.2 Bendix Scanner output in negative print form showing differences in grazing management practices as evidenced by the distinct tonal boundary (fence-line). The dark-toned rangeland is more heavily utilized than the light-toned rangeland and the tone signature resulting from differences on opposite sides of the fence-line is an expression principally of species composition and density.

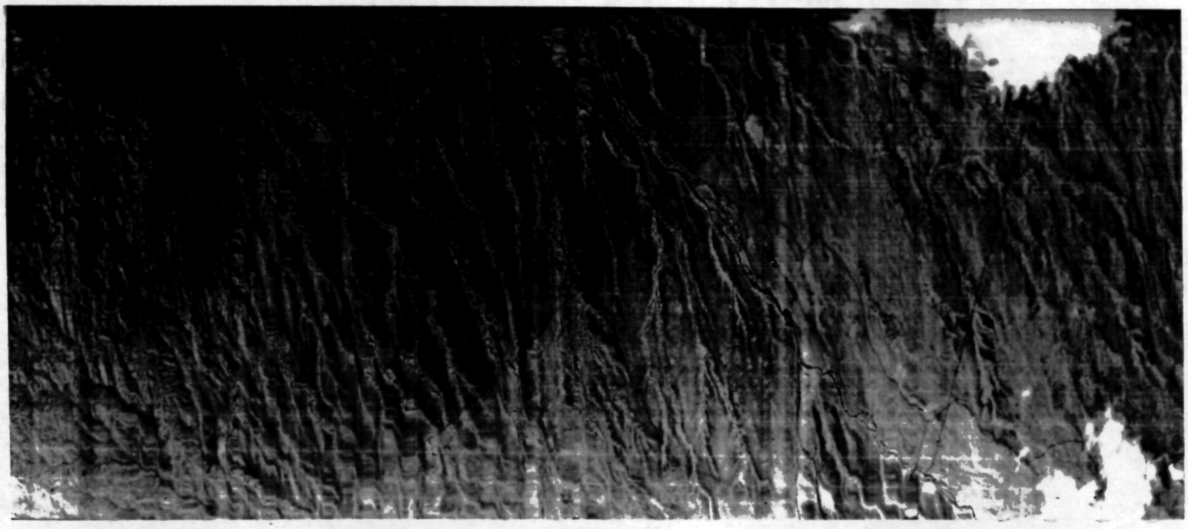
Channel 3: 0.50-0.56u

Channel 4: 0.56-0.62u

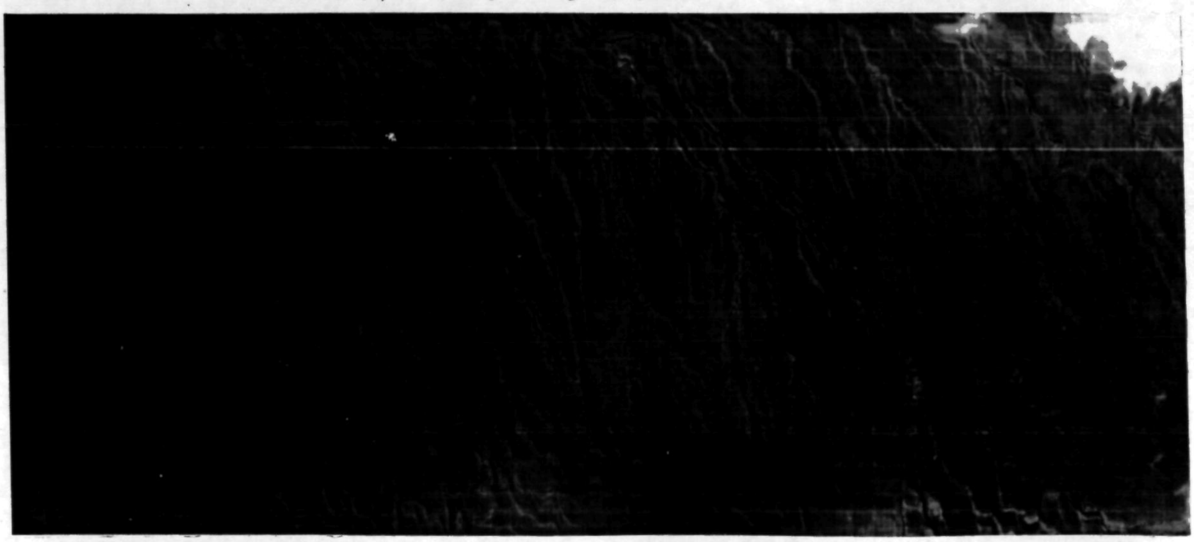
Channel 5: 0.62-0.68u

Channel 6: 0.68-0.74u

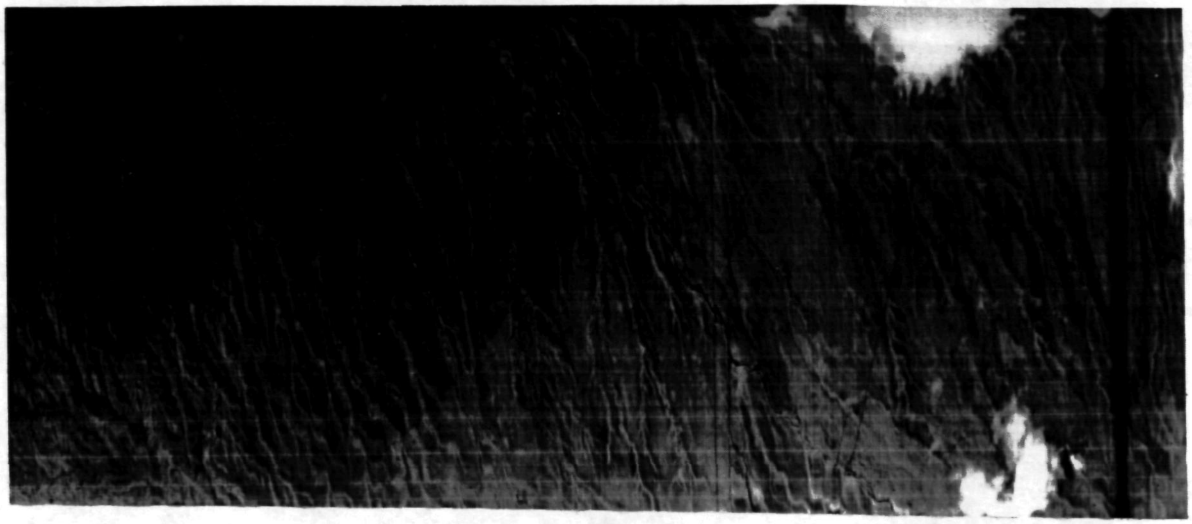
Channel 7: 0.74-0.86u



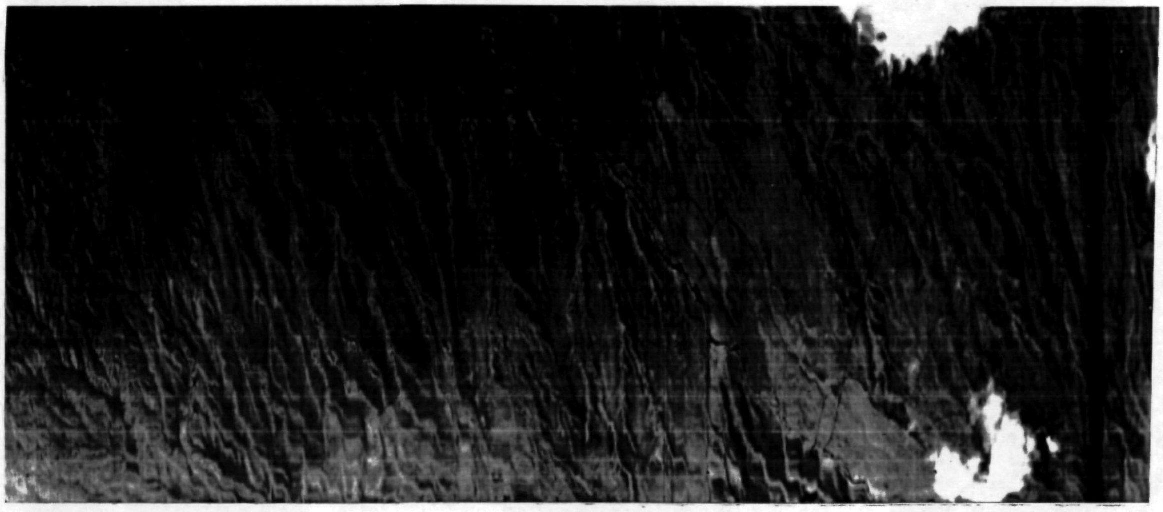
Summation of Channels 3,4 and 5: 0.50-0.68u



Summation of Channels 4,5 and 6: 0.56-0.74



Summation of Channels 6,7 and 8: 0.68-1.0u



Summation of Channels 3,4, 5,6, 7 and 8: 0.50-1.0u

CHAPTER VI

FEASIBILITY TABLES AND AN EXPLANATION OF THEIR USE

If photographs such as those obtained on the Apollo 9 mission are to be useful for surveying the earth's resources, they must be more than aesthetically appealing. The test of their usefulness lies, not in their beauty, but in the feasibility of inventorying certain important earth resource features from a careful study of them. This necessitates our determining how consistently such features can be discerned on the space photography. For each type of earth resource feature, such a determination can be made only by comparing the interpretation of that feature, as made on space photography, with corresponding "ground truth". Furthermore, our findings must be based on a study of areas which are both representative and of sufficient size to yield statistically significant answers.

For some earth resource features (e.g., agricultural fields that are being irrigated or mowed) care must be taken to acquire "ground truth" at almost the same instant as the space photography itself is being obtained. For certain other earth resource features (e.g., reservoir levels, snow levels, timber cutting boundaries, states of crop flowering or fruiting and degrees of water pollution) delays of a few hours or days in acquiring ground truth may be tolerable and for a very few earth resource features (e.g., certain landforms and associated mineral deposits) the acquisition of ground truth at any time in the same "geologic era" may be adequate.

Within the time constraints of this "30-day report" we have made a maximum effort to arrive at statistically significant determinations as to the feasibility of surveying various earth resource features on

space photography. Detailed interpretations were made of both the S065 photography that was obtained during the Apollo 9 mission and also of the hand-held Ektachrome (conventional color) photography that was obtained during the same mission. With the aid of reliable "ground truth" data, analyses currently are being conducted to determine quantitatively the errors of omission and of commission which we made as we sought to survey various types of earth resource features on this space photography. In the meantime, we are able to draw tentative conclusions, most of which we consider to be quite reliable, as to the extent to which each of several earth resource features can be inventoried on such photography. Our results to date are summarized in Table 6-1 (see next page). From a study of those tables it will be noted that one of four feasibility ratings has been assigned wherever possible. The rating symbols that have been used are of the same type as we have used in several previous reports dealing with photography obtained from aircraft rather than spacecraft. The symbols can be defined as follows:

++ signifies that the resource feature is <u>consistently identifiable</u> by most photo interpreters on space photographs flown to the specifications indicated; only rarely is a mistake made

\+ signifies that the resource feature is <u>usually identifiable</u> on the space photographs; however, to avoid numerous mistakes care must be taken that the photo interpretation is done by personnel having a strong background of training and experience in the resource discipline involved (e.g., forestry, agriculture, range management)

\- signifies that the resource feature is <u>usually unidentifiable</u> on space photography flown to the specifications indicated; however, with moderate improvement either in image quality or photo interpretation skill most "-" ratings could be converted to "+"

-- signifies that, important though the resource feature may be, it is <u>consistently unidentifiable</u> on space photography flown to this specifications indicated

TYPE OF EARTH RESOURCE FEATURE	Photographic Film-Filter Combination				
	Black-and-White Photos			Color Photos	
	Pan-58 (Green)	Pan-25A (Red)	Infrared-89B (Infrared)	Ektachrome (Normal Color)	Infrared Ektachrome (False Color)
VEGETATION RESOURCES					
Vegetated or not	-	+	+	+	++
Natural or cultivated vegetation	+	+	+	+	++
Trees, shrubs or herbaceous vegetation	+	+	+	+	++
Hardwoods or conifers	-	-	-	-	+
Individual tree species	--	--	--	--	--
Chaparral, desert shrub or other shrub type	-	-	-	+	+
Individual shrub species	--	--	--	--	--
Annual or perennial herbaceous type	--	--	-	-	-
Individual herbaceous species	--	--	--	--	--
Orchards	-	-	-	+	+
Continuous cover crops	-	+	+	++	++
Individual crop types	--	--	--	-	-
Vegetation density	-	+	+	+	++
Vegetation vigor	-	-	+	-	+

TYPE OF EARTH RESOURCE FEATURE	Photographic Film-Filter Combination				
	Black-and-White Photos			Color Photos	
	Pan-58 (Green)	Pan-25A (Red)	Infrared-89B (Infrared)	Ektachrome (Normal Color)	Infrared Ektachrome (False Color)
WATER RESOURCES					
Deep ponds or lakes	+	+	+	+	++
Shallow ponds or lakes	-	-	-	-	+
Streams and rivers	+	+	+	+	++
Springs and canals	-	-	-	+	+
Water level in reservoirs	-	-	-	+	+
Degree of water turbidity	-	+	-	+	+
Snow line on mountains					
Watercourse boundaries	++	++	++	++	++
Soil moistened by recent rains	-	+	-	+	+
GEOLOGIC, MINERAL, SOIL RESOURCE					
Upland, i.e., eroding mountain slopes vs. bajada	+	++	+	++	++
Bajadas (sediment) vs. bottomland and washes	++	++	+	++	++
Playas	+	+	+	++	++
Igneous rock masses	+	+	+	++	++
Sedimentary rock masses	+	+	+	+	+
Metamorphic rock masses	+	+	+	++	++
Deeply eroded stream and river courses	+	+	-	++	++
Open mining pits	+	+	-	++	++

TYPE OF EARTH RESOURCE FEATURE	Photographic Film-Filter Combination				
	Black-and-White Photos			Color Photos	
	Pan-58 (Green)	Pan-25A (Red)	Infrared-89B (Infrared)	Ektachrome (Normal Color)	Infrared Ektachrome (False Color)
GEOLOGIC, MINERAL, SOIL RESOURCE (Con't)					
Tailing piles	+	+	-	++	++
Broad soil types, i.e., sandy loams vs. clay	+	+	-	++	++
CULTURAL FEATURES					
Urban development	+	+	-	+	+
Urban areas	+	+	-	++	+
Roads, paved	-	-	+	+	+
Roads, unpaved	+	+	-	+	+
Airfields	+	+	+	+	+
Parks, golf courses	+	+	-	+	++
Smelters, mills (smoke plumes)	+	+	-	+	++
Land clearing projects	+	+	+	++	++

The feasibility tables which appear in this chapter are very useful in summarizing much of what we have learned during the first 30 days that Apollo 9 photography has been available to us.

From having made numerous studies of aerial photography comparable to those reported herein for space photography, our group has long since learned to let the ultimate user of earth resource surveys decide whether or not such results are "promising". But whatever their conclusion might be, we also have learned that several factors which are not reflected in the present feasibility ratings can have a decided cumulative effect that will make such results look "more promising". Specifically:

(1) A comparative analysis of sequential space photographs (i.e., those taken repetitively at appropriate time intervals) may facilitate the identification of many earth resource features. This statement is especially true for vegetation resources since, on space photographs, one kind of vegetation may exhibit essentially the same tone or color as others, so that only the presence or absence of vegetation (and something of its density) can be determined. To illustrate this point, let us consider the various agricultural crops grown in the Imperial Valley of California and in Arizona (Chapter 2). In those areas, as in many others, a "crop calendar" such as the following is very useful. (Principal crops grown in the area are barley, milo-maize, sugar beets, alfalfa, asparagus, lettuce, carrots and various kinds of citrus).

(a) Barley is planted in November or December of each year and is harvested the following April; then the area either lies fallow or is planted to a summer crop of milo-maize.

(b) Sugar beets are planted in September or October of each year and are harvested the following July and August.

(c) Alfalfa may be planted at any time but usually is grown on a 3-year rotation; it commonly undergoes mowing and regrowth as many as 6 or 7 times per year.

(d) Asparagus usually is grown on a 4 to 6 year rotation. At certain times during this rotation the asparagus is allowed to go to seed. On those occasions the field will very quickly progress from an apparent vegetation density of less than 5 percent to a density of nearly 100 percent.

(e) Citrus orchards likewise may attain a density of nearly 100 percent, but the time period during which they progress from very low to very high density is several years instead of several weeks.

(f) Finally, carrots and lettuce are very short rotation crops, in addition to which head lettuce tends to be grown only during the cooler months when heads will form.

Even if nothing more than the presence or absence of vegetation in a field--and something of its density--is discernible on space photography, positive crop identification may be possible through the use of sequential space photos and reference to a crop calendar such as this.

(2) For each of several important earth resource features that are to be inventoried, more than 95% of the task is accomplished merely by drawing boundaries on the space photograph that will serve to define where, on the earth's surface, that type of feature ends and some other begins. Then, through the use of a "double sampling technique" (Chap. 1) that employs a limited amount of large-scale aerial photography (or direct on-the-ground observation) the identity of each type of feature can be established. The essential point here is that one usually can discriminate between earth resource features on space photographs even though he may not be able positively to identify each such feature, however carefully he studies the photos.

(3) In the United States and in many of the other parts of the world, most of the earth resources already have been inventoried by one means or another. For certain of these resources the only information that would

be sought (in any operational program) through a study of space photographs would be the changes that had occurred since the last inventory had been taken. For example, this concept is applicable to virtually all timber stands in the United States. Through the use of conventional timber inventory techniques, the volume by species already will have been determined as of some recent year, area-by-area. The resource survey problem for which space photography is to be used may then be merely one of determining changes; e.g., determining what volume of timber by species has been removed in the interim in any part of the forest that has been recently logged or burned, or what volume by species shows evidence of being infested by some insect or disease. Such information usually could be accurately obtained merely by (a) outlining on the space photography each part of the forest where it can be discerned that such recent changes have occurred and then (b) consulting the previously-acquired timber inventory records that give volume by species for each such area.

(4) While all conclusions as to the usefulness of space photographs should have a sufficiently broad statistical base, care must be taken to draw the most meaningful conclusions from those statistics. Again, a specific example will be given to illustrate the point, even though it will be necessary in this instance to extrapolate from our experience in testing aerial photo interpreters and to presume that we will obtain similar results in our forthcoming tests of space photo interpreters. Allowing ourselves this presumption, we can postulate that a group of 40 testees has recently been trained to interpret certain earth resource features on space photography. In a subsequent extensive testing period, an average accuracy of only 60% is achieved. At first this seems to be

a discouraging finding, indeed, and all the more so because it is drawn from such a broad statistical base (40 trainees examining a great many space photo examples). However, closer examination of the results shows that, of the testees who were geologists, six of them scored better than 90% correct answers on those space photo interpretation problems dealing with geologic resources. Similarly, of the six testees having a strong professional background in range management, four scored better than 85% correct answers on those space photo interpretation problems dealing with range resources. Similar results are obtained by those in the test group who are foresters, agriculturists, etc.

When we study the results more carefully, then, we can conclude that the exercising of two measures in any subsequent "operational" earth resource survey based on space photography might improve the accuracy of interpretation to an acceptably high level: (a) limiting each individual to interpreting only the types of earth resource features with which he is familiar by virtue of prior training, experience and motivation; and (b) having done so, eliminate those who still produce unacceptably low accuracies of interpretation.

More complete feasibility tables than those appearing in this chapter will be prepared as we continue our studies of the Apollo 9 photography. These revised tables will appear in our future, more detailed reports. Also, in future reports we will include similar ratings for: (1) space photographs that have been enhanced by the various means described in Chapter 1; (2) aerial photographs that were taken at various flight altitudes and at nearly the same time as the Apollo 9 photographs; and (3) optical mechanical scanner records that also were obtained from aircraft at nearly the same time as the Apollo 9 photographs.

CHAPTER VII

SUMMARY AND CONCLUSIONS

In the introductory chapter of this "30-day report" a description is given of the types of photography that were obtained both on the Apollo 9 mission and on concurrent flights made over some of the same NASA test sites by supporting aircraft. To set the stage for an analysis of this photography, the need for earth resource surveys and the value of aircraft and spacecraft as the platforms from which to make such surveys are then considered. This introductory chapter concludes with a presentation both of the rationale for using multiband photography when making earth resource surveys, and various means by which such photography can be enhanced.

In Chapters II, III and IV, numerous aerial and space photographs obtained in connection with the Apollo 9 S065 experiment are presented and analyzed. Chapter V considers various possibilities for the automated analysis of space photography, even though at the time of report preparation no specific examples based on the Apollo 9 mission were as yet available.

Chapter VI presents several tables that are designed to summarize our findings to date as to the feasibility of conducting earth resource surveys by means of space photography. Also in Chapter VI a discussion is given of several favorable factors which, operating in concert, can greatly improve such feasibility.

While highly encouraging results can be drawn from these preliminary studies of the Apollo 9 photography, it is deemed important to defer the drawing of final conclusions as to operational feasibility until the following steps have been performed, all of which are part of our present

on-going program:

(1) The use of sequential photos as an aid to the interpretation of time-dependent phenomena. (Plans call for six very high altitude photographic flights to be made over selected test sites that were covered by the Apollo 9 photography. These flights are to be made at monthly intervals, beginning on April 23, 1969.)

(2) The implementation of a training and testing program in which 30 to 40 individuals will be employed and the accuracies with which they are able to interpret various earth resource features on space photographs will be tabulated.

In conclusion, it must be emphasized that our group is only one of several groups that are seeking to determine the usefulness of Apollo 9 photography in the inventory of various kinds of earth resources. These other groups share our opinion, however, that the success achieved by the Apollo 9 astronauts in obtaining high quality multiband space photography of selected NASA test sites was very timely. That photography is providing all of this nation's earth resource survey investigators with a much needed opportunity to study at this time both the opportunities that will be presented and problems that will be encountered in 1971 when the first operational multiband satellite, ERTS-A, will be launched. The multiband system scheduled for use in ERTS-A will employ essentially the same wavelength bands as were incorporated in the Apollo 9 multiband camera system. This fact makes even more meaningful the research currently being done on the Apollo 9 photography to establish "tone signatures" for various earth resource features.

Aerial photography and optical mechanical scanner data obtained during the Apollo 9 mission is permitting us to evaluate various double and triple

sampling schemes that will further enhance the usefulness of space photography for the inventory of earth resources. The fact that sequential, very high altitude photography, using these same bands, also is being obtained of the same NASA test sites adds still further significance to analyses currently being made of the Apollo 9 photography.